

# WORKING WATERFRONTS

## THE ECONOMIC IMPACT OF SEA LEVEL RISE ON PORT OF SAVANNAH'S GARDEN CITY TERMINAL & CITY OF DARIEN

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## INTRODUCTION

Coastal Georgia is a diverse region stretching nearly 100 miles and housing over half a million people in the adjacent six counties. It contains some of Georgia's oldest and most historic cities, some of which have grown into major economic engines, and others of which testify to the region's rich cultural heritage. The Georgia coast is home to beaches, marshes, barrier islands, and working communities, which coexist with major cities, manufacturing sites, tourist hubs, vital highway corridors, and one of the nation's largest ports. As such, the working waterfronts of the Georgia coast live within a rich environmental, cultural, and economic system that interconnects them all. These waterfronts are home to diverse industries at different scales including international container shipping, fishing and shrimping, and tourism that benefits from their natural beauty and heritage.

Scientists have observed sea levels rising along the Georgia coast since the 1930s. The National Oceanic and Atmospheric Administration had documented a sustained trend since 1935 of sea levels rising by 2.98 millimeters per year (National Oceanic and Atmospheric Administration 2013). Other sea level rise projections have forecasted that sea level rise will continue and accelerate, potentially resulting in a sea level rise of 1 meter above 1999 levels by 2100 (United Nations 2013). Communities should plan for these effects. By planning now, communities can protect their livelihoods and community treasures with a minimal cost or social disruption compared to acting when disruptions are imminent.

The Georgia Conservancy is a non-profit organization that has worked in throughout the State of Georgia since 1967 to advocate for environmental policies and growth that will protect Georgia's natural resources. It has a long history of engagement and partnership on the Georgia coast that has informed its work and focus. In 2012, the Georgia Conservancy sponsored a studio by graduate students in the School of City and Regional Planning at the Georgia Institute of Technology to investigate the potential impacts of sea level rise in three coastal counties and to detail adaptation opportunities (Keating and Habeeb 2012). The studio found that one meter of sea level rise would inundate nearly one third of the three-county studio area, with a disproportionate impact on parks and conservation land, particularly wetland areas. The team also found significant inundation of residential and waterfront commercial properties, inundation of 13 miles of state and national highways, and the flooding of railroads serving the Port of Savannah, one of the nation's largest container ports. The Georgia Conservancy commissioned the present studio to expand upon the past studio's work on the Georgia coast, particularly addressing sea level rise's economic impacts on the coast and the ripples of this region- and state-wide.

Economic impacts are one of the most understudied, but important aspects of sea level rise because the analysis captures relationships that remain hidden from other perspectives. Sea level rise threatens businesses and vital infrastructure in ways that may affect Georgia's economic vitality and potential. Sea level rise threatens large and small businesses, as well as families and individuals along the coast. Small businesses and economically disadvantaged households may have fewer resources with which to



respond, creating a disproportionate impact. Moreover, certain industries such as fishing and tourism depend on the coast's natural resources. Finally, an economic analysis reveals relationships between seemingly unconnected locations. These relationships involve employees, exporters, consumers, business operators, and others who are not physically located on vulnerable land but whose life and livelihood is linked with the coast. They are the invisible stakeholders that need to be incorporated into sea level rise discussions.

The present studio at the Georgia Institute of Technology describes and quantifies sea level rise's impact on coastal Georgia's economy and the potential repercussions. Sea level rise has the potential to affect communities equally but differently, so the study team focused on two very different sites to capture the diverse impacts. One is the Garden City Terminal at the Port of Savannah, which is one of the country's largest container terminals and the second busiest container exporter by tons (Georgia Ports Authority 2013). The terminal is expected to continue rapid growth facilitated by a multi-million dollar port deepening project.

While the Port of Savannah is a major economic engine for the entire state, the City of Darien—which is the second study site—is a quintessential small, coastal town. Darien has nearly 2,000 people with a heritage extending back to 1736. Darien's economy is heavily dependent on a few industries, namely fishing, tourism and small business, and residential real estate, which makes it more vulnerable to sea level rise than larger cities. Both the Port of Savannah and the town of Darien have diverse constituents that will be impacted based on what is of value to them. The impacts on one site should not be understood to be greater than the other but rather attests to fundamental differences in character.

While the study team analyzed economic impacts on each site, it took different approaches depending on economic characteristics. Whereas the research team analyzed the Port of Savannah using a traditional economic impact study to measure the effects of a port shutdown, it approached the City of Darien entirely differently, conducting in-depth industry studies to draw connections between sea level rise and local livelihoods. Each methodology was chosen based on site-specific characteristics, such as industry makeup, economic scale, and available data.

The studio's analysis is intended to inform elected officials, residents, industry, community planners, and others as they prepare for sea level rise on the Georgia coast. Moreover, the analysis reveals that sea level rise is not just a coastal issue, but rather is important at regional, state, and even national levels because of the accompanying economic impacts.

## Executive Summary for Garden City Terminal Section

The Garden City Terminal at the Port of Savannah is one of the largest and fastest growing container ports in the country, making it an economic engine locally and nationally. The Terminal is an integral economic component on several scales: locally, it supports many households in and around Chatham County; regionally, the port supports wider distribution networks and regional agriculture and manufacturing; and nationally, the port serves as a gateway to access markets across the globe. Therefore rising sea levels projected over the next 100 years make port disruptions an important economic threat on a variety of scales. This report describes the economic threat that sea level rise poses to port and port-related operations through permanent inundation, worsening storm surge, and other environmental changes at local, regional and statewide scales. The team drew on research by Keating and Habeeb (2012) and created new tools for assessing the potential impacts on jobs, property, transportation links, and other businesses. The intent is to provide actionable projections for business leaders, policy makers, and individuals in areas that may eventually have to respond to the effects of sea level rise.

A one meter rise in sea level would have a limited impact on Garden City Terminal facilities based on sea level rise calculations conducted by the study team. The team's analysis suggests sea level rise will cause minor flooding along the Terminal's storm drainage canal, which could change maintenance and cargo handling practices at the Terminal and impose costs on the Georgia Ports Authority. In addition to permanent inundation, the study team also conducted an economic impact analysis that calculates the loss of economic activity to the State of Georgia in the event of three hurricane scenarios to determine the economic impact of sea level rise from reduced operations at the port. Storm surge threatens to magnify the potential effects of sea level rise since higher sea levels provide a higher base for hurricane-driven storm surge. Below are some of the report's major findings regarding storm surge.

- The Garden City Terminal's location on the Savannah River makes it vulnerable to storm surge, and sea level rise is likely to increase the port's vulnerability by reducing its height above the water. Moreover, Chatham County's warehouses are more vulnerable to storm surge than to permanent inundation, which sea level rise will also worsen.
- Large portions of the Garden City Terminal are expected to flood under a category 1 hurricane storm surge. Sea level rise is like to increase the flood depth and extent, worsening disruptions to port operations. Category 5 storms could cause devastating flooding over 25 feet above terminal ground, which sea level rise would make even more destructive.
- Warehouses around the Port are very vulnerable to high storm surges. Sea level rise could increase the number of warehouse parcels affected by storm surge in a category 1 hurricane by 50%. Almost all warehouses would be affected by high level storms, and sea level rise would worsen inundation.

To determine the economic impact of a hurricane and storm surge at the Terminal, the team used economic input data from the University of Georgia's 2012 report, "Economic Impact of Georgia's Deepwater Ports" and reports on post-hurricane recovery periods at other ports. Using this information, the study team quantified the impact of sea level rise on the Garden City Terminal in terms of overall output and gross domestic product for the State of Georgia.

- The total economic impact of a category 1 hurricane on Georgia's economy in terms of output is \$1,099,371,223, and in terms of State GDP is \$537,021,699. This includes direct, indirect and induced impacts.
- The total economic impact of a category 3 hurricane on Georgia's economy in terms of output is \$1,539,119,712, and in terms of State GDP is \$751,830,379. This includes direct, indirect and induced impacts.
- The total economic impact of a category 5 hurricane on Georgia's economy in terms of output is \$13,500,278,613, and in terms of State GDP is \$6,594,626,469. This includes direct, indirect and induced impacts.

On a broader geographic scale, the team also looked at sea level rise's impact on warehouses in Chatham County, commute patterns, and road and rail networks.

Chatham County has 437 warehouses, of which are large number near the port and the I-95 corridor process large amounts of port-related traffic. Analysis revealed that warehouses have minimal direct vulnerability to permanent inundation. One meter of sea level rise floods 1.5% of warehouse property area. Warehouse buildings in all of Chatham County have an estimated value of \$896 million, of which approximately \$16 million, or 1.8%, may be affected by permanent inundation.

The results of the commuter analysis show that two areas stick out the most with regards to vulnerable terminal employees: Unincorporated Chatham County and Unincorporated Liberty County. Unincorporated Chatham County is home to 37 terminal employees and is expected to have 83.9% of its land inundated. Unincorporated Liberty County houses 30 terminal employees and will likely experience a 45.7% inundation of land.

The study team overlaid one meter sea level rise inundation maps over the coastal Georgia road and railroad network to determine the extent to which sea level rise will affect the transportation network. Using this data along with roadway bridge construction cost estimates, the study team then determined the cost of rebuilding inundated roadway segments as bridges. This analysis revealed that 22.59 miles of major coastal Georgia roadways will likely be inundated under one meter of sea level rise. In order to restore these roadways, the community would have to build 336 total bridges at a construction cost ranging from \$350-922 million in current value. Additionally, 84 segments, totaling 14.04 miles, of railroad would be inundated under one meter of sea level rise.

## Executive Summary for Darien Section

In the section on the City of Darien, the analysis focused on three main industries, commercial fishing, tourism and small business, and residential real estate, as well as local commuting patterns, to assess the economic impacts of Sea Level Rise (SLR) over the next 100 years.

In assessing the impacts to commercial fishing, the report focused on the relationship between SLR and the city's unique coastal ecosystem over the next 100 years. Within the commercial fishing industry, shrimping, crabbing and jellyfish processing were looked at in the most detail, as they are the largest industry catches. The coastal wetlands are essential to this industry. They provide a food source, shelter and habitat to these commercial species. Salinity is the most important measurement when determining the future growth of coastal wetland ecosystems, and therefore salinity levels have a direct impact on the health of each species, the stability of their habitat, and their vulnerability to diseases and parasites that can crash the population. To better understand habitat and salinity level changes over the next 100 years, the studio team ran a SLAMM (Sea Level Affecting Marshes Model) model using data from the South Atlantic Migratory Bird Initiative. The model demonstrates that there will be a 50% reduction in the amount of salt marsh on the Georgia coast, a habitat that is extremely important to shrimp and crab species.

Tourism may suffer if sea level rise degrades wetlands and other natural attractions around Darien. Nature and heritage based tourism are an important economic driver for the City of Darien. Of particular importance to Darien's tourism are historic sites such as Fort King George, the historic downtown, the Coastal Heritage Trail and the coastal wetland ecosystem. Many of these sites are crucial to the success of the tourism industry and are at risk of being permanently inundated by the rising sea levels over the next 100 years. The community's key historic sites—including Fort King George and the Butler Island Rice Plantation—are likely facing permanent inundation. It will be important to the local economy to protect historic and natural tourist attractions as much as possible through protection or relocation. Tourism may also present an opportunity for public outreach on sea level rise through education about its effects on Darien.

Small businesses are often severely affected in the face of flooding and Darien has a number of coastal businesses that would be adversely affected by SLR. Fortunately Darien is located on a 30 foot bluff, and the direct impact to the community's small business industry is expected to be minimal.

In total, 75 residential buildings in Darien are predicted to be damaged by SLR. While many of the residential properties in Darien will not be affected directly by SLR, increased storm surge due to higher sea level will likely impact a larger percentage of properties. One of the implications here is for the National Flood Insurance Program, which is currently phasing out subsidized policy rates. Also, secondary residences and properties that have experienced severe or repeated flooding will see a 25% annual increase in their rates. Greater flood insurance rates will put an increased financial strain on homeowners and small business owners. Of particular concern in Darien is the

effect these costs will have on seasonal home owners that represent 7.5% of all of the housing stock in Darien.

The report also looked at the commuting patterns of workers that live in Darien in order to determine if SLR will affect their places of work. This was done using the Census Bureau's online mapping program, "On the Map". Overall, out of 511 workers, 33 commute to a place that will be inundated by SLR. This represents 6.5% of Darien's workforce. Furthermore, the majority of workers travel outside the city to work. If this trend continues, more people may start to commute to affected areas.

In examining adaptation strategies, the report identified strategies for these three main industries. Traditional adaptation strategies include armoring of the shoreline, retreating from the shoreline, or considering measures that accommodate SLR. The report highlights the importance of using tools and practices that encourage community involvement. For example, three communities in coastal New Hampshire have used an innovative program called COAST for a community-driven SLR planning process. It is important for the City of Darien and other local communities to communicate with stakeholders, educate at risk populations, and involve community members in a way where they can decide the adaptation strategies that are most appropriate for the local area that they live in.

In conclusion, key findings suggest that flexibility is needed in order to adapt to changing species populations in the commercial fishing industry. Also efforts need to be made to produce policies that will preserve the existing wetlands and coastal habitats. Land use controls should be used to protect existing wetlands and adjacent parcels in the case of wetland migration. Important tourism sites should be protected or relocated, and public education opportunities through the tourism industry should be taken advantage of. Many small businesses may face disruption of their operation or long term relocation. Lastly, the residential real estate industry will be increasingly impacted by flooding, and an increase in rates for flood insurance. These increases may make home owning overly expensive for some residents.

## Garden City Terminal Introduction

The Garden City Terminal is the main container shipping terminal at the Port of Savannah, Georgia, and it is one of the largest and fastest growing container shipping terminals in the Southeastern United States. The terminal allows retail suppliers such as Home Depot, IKEA, and Target to bring overseas merchandise to American consumers from all over the world. Simultaneously, the terminal supports an even higher volume of exports by weight to Europe and other destinations, supporting numerous agricultural and manufacturing jobs in the southeastern United States. However, the port's economic links are not just related to the consumers and producers whose goods transit through it; the port also supports several thousand jobs on-site and many more jobs in the surrounding warehouses and distribution networks that carry freight to and from inland distributors, stores, and processors. As such, the port is an integral economic component of several scales: locally, it supports many households in and around Chatham County; regionally, the port supports wider distribution networks and regional agriculture and manufacturing; and the port serves as a gateway to access markets across the globe.

The Terminal has grown tremendously to become an economic powerhouse, but its location on the water to be accessible to ocean-going ships makes it potentially vulnerable to the sea level rise. Sea levels are projected to rise by approximately 3 feet over the next 100 years. While the rise will not inundate the port, it will decrease the dock heights relative to the water and may increase vulnerability to flooding under severe storms, salt water damage, or decreased efficiency. Sea level rise may also threaten off-site roads, rails, and warehouses that connect the port with inland customers. These changes may disrupt port operations or require expensive retrofits to maintain operations.

This project will review the likely economic effects of sea level rise at the Garden City Terminal over the upcoming 100 years. It draws on research by Keating and Habeeb (2012) and includes new tools for assessing the potential impacts on jobs, property, and other businesses. The intent is to provide actionable projections for business leaders, policy makers, and individuals in areas that may eventually have to respond to sea level rise effects. While port planning timelines generally occur over 10 years and some businesses have an even shorter timeline, it may be possible to mitigate or avoid negative impacts by accounting for long-term sea level changes early to build safety and resiliency into early design, policy, and business decisions.

# Containerized Shipping

## Industry Background

Containerization has emerged as a major force in growing international trade, integrating land and sea transportation modes, and transforming the economic dynamics of port communities. Containerization is a simple idea: it puts cargo of all types into standard-sized boxes that can be loaded onto ships, trucks, or trains with a standardized system no matter the types of cargo contained.

Freight shipping did not begin this way. Goods can be transported as dry bulk, liquid bulk, neobulk, breakbulk, or containerized cargo (Hoel et al. 2011). While commodities like cement, automobiles, coal, petroleum products, and grain are transported in bulk, nearly all other commodities are transported as containerized cargo (Cudahy 2006). However, shippers did not always use standard containers to transport cargo. Up until the 1950s, the cargo that is containerized today was handled as break-bulk cargo—where goods were loaded on pallets and each pallet was individually transported from the warehouses to the ports. At the ports of origin, each pallet was carefully unloaded from truck and railcars and loaded onto the ship to minimize potential damage. At the destination ports, the pallets were carefully unloaded from the ship and loaded onto trucks or railcars that carried them to distribution centers. This made handling cargo a frustrating and time-consuming process (Hoel, et al. 2011). Often, items were unusual shapes or sizes that could not be palletized. Therefore, breakbulk shipping required armies of longshoremen worked at each port to load cargo of different shapes and weights into ships with an equal diversity of arrangements. Longshoremen learned to fit cargo into irregularly shaped spaces, to account for the order in which cargo would be unloaded at different ports, and to accommodate different types of commodities and packaging in a single ship (Levinson 2006). The breakbulk ships had lots of open space under deck to accommodate different types of cargo (Levinson 2006). Loading and unloading was labor intensive, but it sustained a large labor force and working class communities adjacent to ports.

While shipping in containers had existed since the early 1900s, different railroads and shipping companies used different sized containers and the practice was not widespread (Levinson 2006). The post-World War II shipping industry used large amounts of labor to accommodate cargo in break bulk vessels, though the industry's protection from competition did not pressure it to increase efficiencies (Levinson 2006). The shipping industry's comfortable position began to change with pressure from the trucking industry, which had heretofore operated very differently from shipping companies.

In 1937, Malcom McLean, a truck company owner from North Carolina, became annoyed with the pace of the process when watching his shipment of cotton, along with other cargo, being slowly and painstakingly loaded onto a ship bound for Istanbul (Cudahy 2006). It was this frustrating event that led McLean to the idea that he could speed up the shipping process by loading truck trailers directly loaded onto ships (Cudahy 2006). These trailers would be loaded by the shipper at the origin and

unloaded at the destination, thus reducing the handling of the cargo to two points. Later, in the 1950s, McLean acted on this transformative idea. McLean purchased a tanker company and retrofitted its ships with raised platforms, called spar decks that could be used to secure the truck trailers. Finally in 1956, the first containership, the *Ideal X*, was loaded in Newark with 58 trailers that he had made detachable from the chassis (Cudahy 2006; Levinson 2006). When the container ship arrived in Houston, the containers were unloaded from the ship and attached to running gear at the dock, thus marking the completion of the first containership voyage (Cudahy 2006). The new practice required new equipment, including a tanker ship retrofitted to carry containers, a new dockside gantry crane to handle containers, and trailer bodies that were detachable from the chassis.

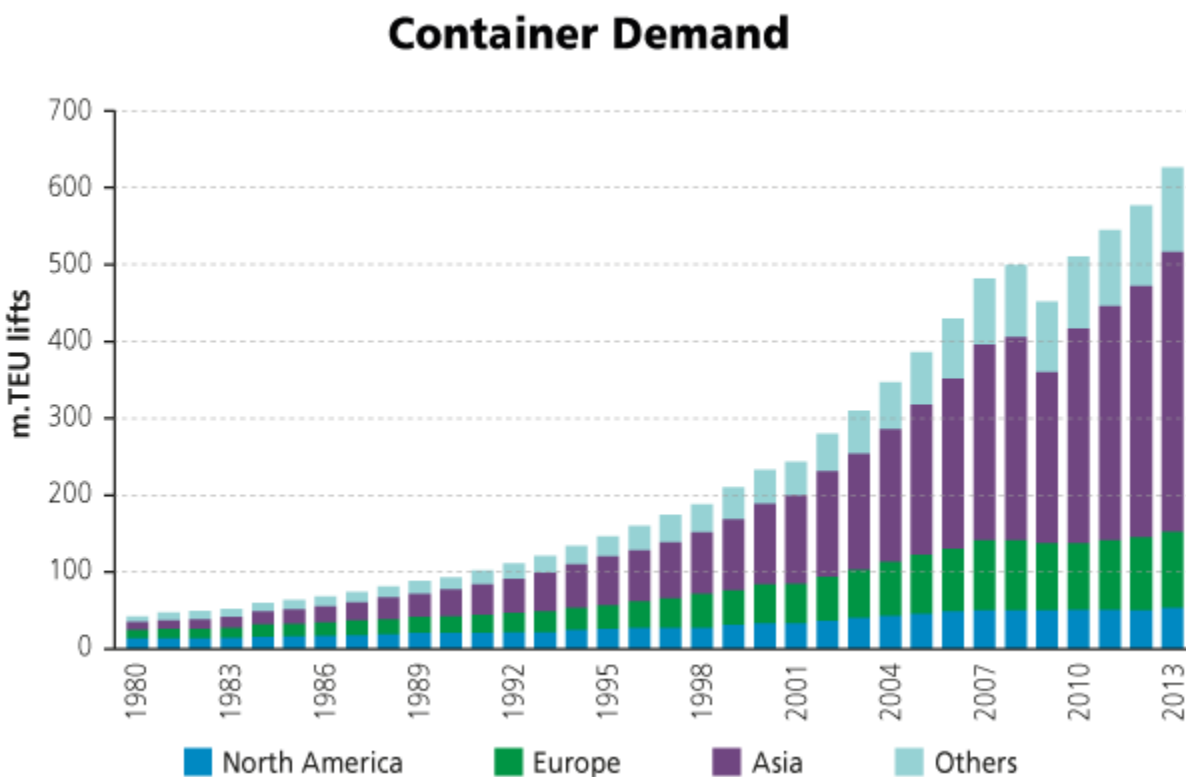
Around the same time other shipping companies, including Matson on the West Coast, implemented similar containerization plans. Over the next several years, the U.S. Maritime Administration and standards organizations arrived at an enforced container size standards based on ten-foot length increments. Producers also developed a locking mechanisms that allowed cranes to attach to containers at its four corners automatically to be lifted onto trucks, trains, or ships. The locking mechanisms further sped container operations and reduced labor. Before containerization, only 20 tons of break-bulk cargo could be loaded per hour by a crew of 20. In comparison, 400 to 500 tons of containerized cargo can be loaded per hour using 1 crane and a crew of 10 workers (Hoel et al. 2011). This means that a break-bulk ship that would often take a week to unload and reload, could be unloaded and reloaded in only six hours as a containerized ship with the same amount of cargo (Hoel et al. 2011). Containerization spread in several steps over the next decades:

- Early 1960s: Containerization began to spread from McLean, Matson, and early adopters to a wider array of companies (Levinson 2006). Containerization created substantial efficiencies in ship utilization and cargo handling, in some cases reducing the cost per ton by nearly 90% (Levinson 2006).
- Late 1960s: Containerization began to be adopted in Pacific shipping. This prompted container ship orders (Levinson 2006).
- Late 1970s: Containerization and larger ships combined with truck and railroad deregulation in the late 1970s to reduce freight costs even further (Levinson 2006). Reduced transportation costs made it economical to ship raw and intermediate goods long distances to markets or further processing, which contributed to globalized supply chains (Levinson 2006).

As containerization spread, communities became increasingly reliant on their ports to connect them with global supply chains (Levinson 2006) even while containerization eliminated many—in some cases most—of the freight handling jobs at ports (Levinson 2006).



The early days of container shipping established a mechanism that facilitated global trade and managed freight flows efficiently at ports such as Savannah. Time and cost savings have allowed containerized shipping to grow tremendously over the past fifty years. Containerization allowed shippers to provide a cheap supply of global freight movement that was soon met with an enormous latent demand. From 1980 to 2006 international cargo transported in containers grew from 36.4 million twenty-foot equivalent units (TEU) to 442 million TEUs and by 2007, 50% of international water-transported cargo was containerized (Hoel et al. 2011). This trend of increasing demand for containerized shipping is expected to remain in the future (Hoel et al. 2011). Figure 1 below shows the exponential increase in containerized shipping that has occurred over the past decades.



**Figure 1: Containerized freight demand**

*Source: BIMCO 2012*

The containerization movement has changed many aspects of the shipping industry, most notably port design. Before containerization, cranes onboard the ships loaded and unloaded cargo which was then stored in warehouses. Today, container ships do not have cranes onboard, and container ports have had to provide cranes at the dock for loading and unloading cargo. Additionally, with containerization, the need for warehouses was eliminated, so warehouses have been removed from container ports and replaced with open land for stacking containers (Hoel et al. 2011).

## Future Shipping Trends

There are some future trends and activities that will also lead to many more changes in the shipping industry. One of these trends in containerized shipping has been the move to build larger ships. This is because the unit cost for transporting a container decreases with larger ship sizes. For example, an 8,000 TEU ship has an 18% to 24% cost savings over a 4,000 TEU ship which in turn has a 30% to 40% cost savings over a 2,500 TEU ship (Hoel et al. 2011). Ship sizes are expected to continue increasing as they have since the size of the largest container ships jumped to approximately 12,500 TEUs with the launch of the Maersk Emma class in 2006 (Rodrigue 2010a).

The trend of increasing ship size has some major implications for container ports. As these container ships continue to increase in size, ports will need to increase the size of on-dock cranes, the on-site container storage capacity, channel widths and depths, and the capacity of railroad and truck facilities. A current issue for East Coast and Gulf Coast ports in the U.S. is the inability of the Panama Canal to accommodate these larger ships. At present, only ships with a capacity of 5,000 twenty-foot equivalent units (TEU) or less are able to navigate the canal. These ships are called Panamax. However, the capacity limit is expected to change in 2014 (Hoel et al. 2011). A third set of much larger locks is being built to allow larger vessels to cross the isthmus and directly access the East Coast and Gulf Coast ports from Asia. Today, 30% of working ships and most of the ships on order are post-Panamax (Bank of America 2013). The completion of this project will place pressure on East Coast and Gulf Coast ports to expand capacity to accommodate the increased demand for containerized shipping (Hoel et al. 2011).

While the Panama Canal expansion is generally expected to increase the size of ships and general traffic volume to East Coast American ports such as Savannah, several eventualities could delay or derail the projected increases. Rodrigue (2010b) highlights the complexities involved in the global freight distribution system that make it prone to unexpected changes in flows. The shipping traffic configuration after the Panama Canal expansion will depend on how shipping companies rebalance the cost, time, and reliability criteria that providing shipping competitive advantage. This shipping reconfiguration may not be as straightforward as many analysts have predicted (Rodrigue 2010b). One of the reconfigurations that was predicted but no longer appears likely is the “Fourth Revolution” in global shipping (Ashar, 2006). The Fourth Revolution was supposed to follow the proliferation of containerization, intermodalism, and transshipment by creating a global east-west north-south grid of shipping services with intensive transshipment at a limited number of logistics hubs. This reconfiguration might have resulted in ports such as Savannah being served by smaller feeder ships from a nearby transshipment hub. However, high transshipment costs are holding off the Fourth Revolution and causing shipping companies to retain the existing configuration, in which container ships ply routes back and forth between major ports, such as Shanghai and Savannah (Ashar 2006).

Increasing wages in China may change container shipping configurations. China has been a primary production center for goods consumed in America and those shipped in

containers to the Port of Savannah. Wages are already increasing in China, and China's domestic consumption is likely to significantly increase as well, which may cause producers to seek lower cost production sites, such as Southeast Asia, South Asia or Latin America (Rodrigue 2010b). Moreover, Rodrigue (2010b) asserts that weak American economic growth and an aging population may hinder the consumption growth that drives imports to U.S. ports.

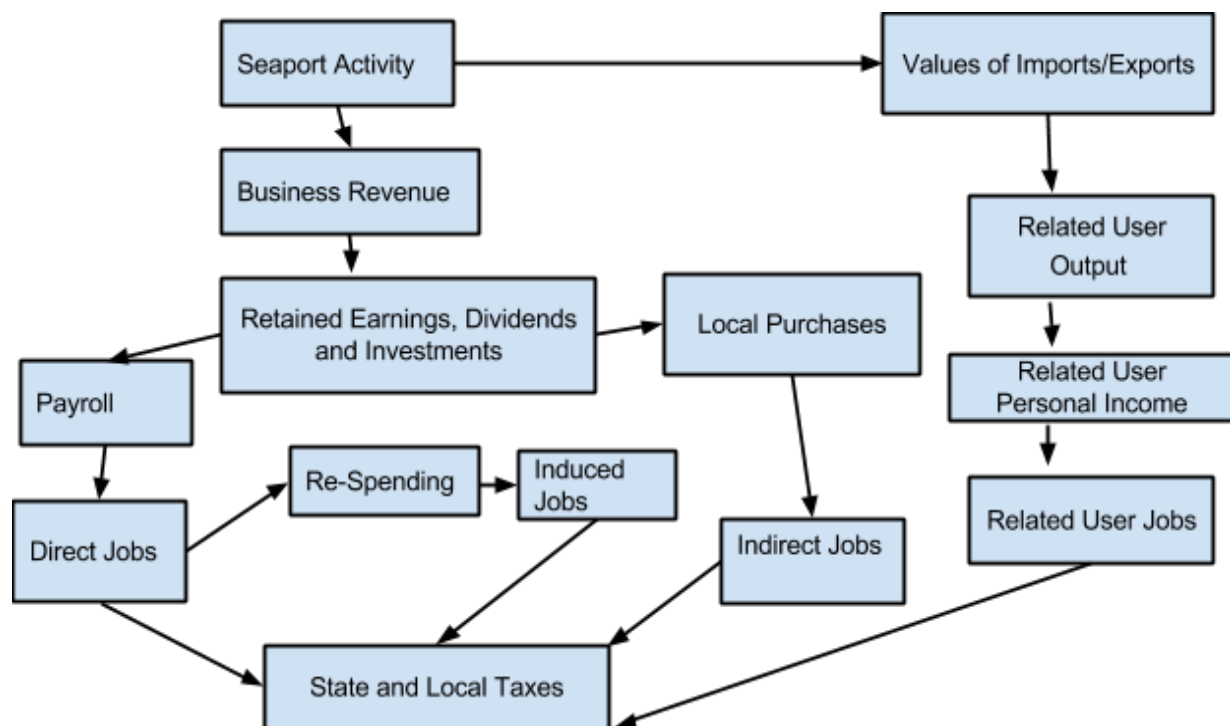
Rodrigue (2010a) believes that predictions about future container shipping increases may be exaggerated and instead that container shipping is reaching maturity, after which it will be marked by slow growth. Past projections made by shipping companies proved overly optimistic, partially due to the 2008 recession, leaving the container shipping industry with a glut of capacity relative to demand (Reuters 2013). Organizations, including the Georgia Ports Authority and the Panama Canal Authority are making enormous investments on predictions of significant container traffic increases to U.S. ports. While these increases are likely, unpredictable economic factors will shape container shipping's future amounts and configurations.

Finally, climate change—the same phenomenon driving sea level rise—may ultimately impact long-term shipping configurations. Arctic ice has been melting at increasing rates since the 1970s, and Arctic summers may be ice free as early as 2020 (*The Economist* 2012; Borgerson 2013). Melting ice may open up the Arctic to shipping. The first ships began going between Europe and Northeast Asia by passing north of Russia in 2010 (Borgerson 2013) and the Northwest Passage above Canada is likely to become passable between 2040 and 2059 (Smith and Stephenson 2013). Both of these routes offer time savings compared with the Panama and Suez Canals, but they remain speculative (Panama Canal Authority 2006). Moreover, a survey by Pelletier and Lasserre (2012) of ocean carriers showed that most container shippers did not take the northern routes seriously because of the unreliability, remoteness, expense of changing shipping schedules each year, need for icebreaker escort, high insurance costs, and lack of intermediate stops.

## Sea Level Rise Impacts on Ports

As a society we depend on ports for the public goods they provide (Becker et al. 2013). Ports are a gateway to domestic and international trade, connecting individual countries and industries to the global economy. As noted above, the advent of containerization and other technological advances in marine shipping over the last century have led to an explosion of marine traffic and a subsequent expansion of ports and port-related industries (Fitzgerald et al. 2008). In addition to playing a key role in trade, ports create jobs, generate wealth, and promote the expansion of related and nearby industries and cities. Industries locate near ports so that they are able capitalize on direct access to world markets through the port and on transit links extending from the port to inland rail and road networks. Port industry and port users rely on the efficiency of these inland transportation networks to move imports and exports to distribution centers across the country (Wright 2013).

Ports not only play a critical role in supply chain networks that move products to manufacturers and consumers, but they also generate substantial economic activity in the global economy. Ports are critical infrastructure that serve as engines of economic growth and development (Nurse-Bray et al. 2013). According to a study commissioned by the American Association of Ports Authorities (AAPA), deepwater seaports generated approximately 13.3 million jobs (471,089 direct jobs, 543, 638 induced jobs, 310,804 indirect jobs, and 12 million with importers, exports and port users), and \$3.2 trillion dollars in total economic activity to the United States economy in 2007 (Martin & Associates 2008). Figure 2 graphically demonstrates how port activity impacts the local, regional and national economies (Martin & Associates 2008).



**Figure 2: Seaport impacts on local, regional, and national economies**

Source: Martin & Associates, "The Local and Regional Economic Impacts of the US Deepsea Port System, 2007." June 6, 2008

Ports are likewise critical infrastructure in Georgia. In addition to several small ports along Georgia's eastern coast, Georgia has two deepwater ports, the Port of Savannah (Garden City Terminal and Ocean City Terminal) and the Port of Brunswick, both of which significantly contribute to Georgia's economy. Over the past decade, Georgia Ports Authority (GPA), the quasi-governmental entity that owns both the Port of Savannah and Port of Brunswick, commissioned the University of Georgia's Selig Center for Economic Growth to conduct research on the ports' economic impact on Georgia's economy. A summary of the findings from 2003 to 2011 is shown in Table 1. Note that the figures are in constant dollars for the years shown and have not been adjusted for inflation.

**Table 1: Georgia Deepwater Ports (Port of Savannah and Port of Brunswick)**

<b>Year</b>	<b>Sales (<i>in billions</i>)*</b>	<b>State Gross Domestic Product (<i>in billions</i>)**</b>	<b>Income (<i>in billions</i>)***</b>	<b>Employment (<i>full and part-time</i>)****</b>	<b>Taxes (<i>federal, state &amp; local, in billions</i>)</b>
<b>2003</b>	\$35.4	\$17.1	\$10.8	275,968	\$4.6
<b>2006</b>	\$55.8	\$24.8	\$14.9	286,476	\$6.3
<b>2009</b>	\$61.7	\$26.8	\$15.5	295,443	\$6.1
<b>2011</b>	\$66.9	\$32.4	\$18.5	352,146	\$7.0

Source: *Economic Impact of Georgia's Deepwater Ports, FY 2011*, Selig Center for Economic Growth, Terry College of Business, The University of Georgia.

\*Gross receipts, plus or minus inventory.

\*\*State GDP consists of employee compensation, proprietor income, other property income, and indirect business taxes.

\*\*\*Income encompasses all forms of employment income, including wages, salaries, and proprietors' incomes. The income figure does not include non-wage compensation, transfer payments or unearned income (Humphreys 2012).

\*\*\*\*Employment includes total wage and salary employees, and self-employed persons (Humphreys 2012).

According to Table 1, the total economic impact of the Port of Savannah and the Port of Brunswick on Georgia's economy in 2011 was \$66.9 billion dollars, or 9.5% of Georgia's total economic output for the 2011 fiscal year. This amount represented the sum of the direct, indirect, induced economic impacts (Humphreys 2012). In the 2011 study, Humphreys of the Selig Center for Economic Growth noted that using sales as a measure of economic impact was problematic, however, because it included the value of inputs produced by other industries and therefore double counted some economic impacts. Humphreys suggested that GDP, income and employment figures are more realistic measures of economic impact (2012).

Turning again to Table 1, the Selig Center estimated that Georgia's deepwater ports contributed \$32.4 billion in state gross domestic product (GDP) in 2011, and generated 352,146 full- and part-time jobs throughout the state in terms of direct, indirect and induced impact (2012). The employment figures were further broken down by county. According to the data, the two deepwater ports supported 37,319 full- and part-time jobs in Chatham County, Georgia where the Garden Terminal of the Port of Savannah is located. With the proposed dredging of the Savannah River to open the Port of Savannah to post-Panamax ships, Georgia's ports will continue to play an important role in the local, state and national economies.

## The Effect of Sea Level Rise on Ports

Climate change, and sea level rise specifically, threatens the viability of ports across the globe. According to a United Nations Report on Climate Change, climate change may impact ports and areas beyond that are around or connected with ports because of the physical capital, employment, and supply chains that are linked with port operations (UN Report 2011). Ports will be particularly affected by rising sea levels because of their location in low-lying coastal zones. Considering that trade by water accounts for 90% of the world's freight shipments, the economic impacts of sea level rise will be significant at a local, national, and global level (Becker et al. 2011). Moreover, the strong interdependence between ports in developed and developing countries may become problematic in future years if ports fail to invest in the improvements and adaptation strategies necessary to prepare for rising sea levels and changing climatic conditions (Becker et al. 2013). A delay at one port, whether climate change-related or otherwise, can cause consequent delays in operations at ports around the world and substantially disrupt global logistics networks.

Sea levels will continue to rise at a quickening rate over the next century due to continued ocean warming and increased loss of mass from glaciers and ice sheets, and the rate of global sea level rise will “very likely” exceed the rate in past years (IPCC 2013). In Georgia, climate scientists have projected that sea level will rise by at least one meter along the Georgia coast over the next one hundred years (Keating & Habeeb 2012). This one meter rise in sea level is similar to estimates used by researchers looking at the impact of sea level rise on international deep-water ports and global shipping (Hallegette et al. 2011). Though only a handful of studies have looked specifically at sea level rise’s impact on ports and port activities, several recurring themes have emerged from these studies. Broadly speaking, trade, shipping, and the port communities will be impacted by increased sea levels (Wright 2013). More specifically, rising sea levels generally affects port infrastructure, operations, employment, and supply chains directly and indirectly in the following ways: (1) flooded or eroded infrastructure in and around the port; (2) decreased port operations and efficiency; (3) increased maintenance costs; (4) inadequate bridge clearance from rising sea levels; (5) increased susceptibility to storm surge; (6) groundwater contamination from chemicals stored near waterfronts; (7) compromised supply chains, including transit networks that extend into low-lying areas and port facilities; and (8) employment disruption or loss.

### Flooded or eroded infrastructure in and around the port

The most obvious impact of sea level rise will be on land or infrastructure that is permanently inundated (California Coastal Commission 2001). Structures and land that are partially submerged at high tide will likely be permanently inundated by a one (1) meter rise in sea level (California Coastal Commission 2001). Researchers in California recently conducted a study estimating the economic costs sea level rise will have on the state’s ports, roads, rails and buildings. Specifically, the study looked at the Port of Los Angeles-Long Beach, which handles 45–50% of the containers shipped into the United States, and surrounding road, rail and power facilities (Herberger et al. 2011). To determine direct damage to buildings in the port and coastal areas, the California



researchers used a Hazus model developed by FEMA. This model uses the economic value of buildings to estimate direct economic losses based on the repair and replacement of damaged or destroyed buildings and their contents, and includes: 1) cost of repair and replacement of damaged and destroyed buildings, 2) cost of damage to building contents, and 3) losses of building inventory (contents related to business activities) (Herberger et al. 2011). Hazus is discussed more fully below.

To determine the impact of rising seas on infrastructure, researchers estimated the miles of roadways and railroads at risk by overlaying the GIS inundation and erosion hazard layers with transportation data published by TeleAtlas (Herberger et al. 2011). The model used had to make many assumptions about the road and railroad networks because not much was known about the elevation of the actual road and rail infrastructure outside of what high resolution maps shows. The maps were produced by a system called Light Detection and Ranging, or LIDAR, in which light reflection determines ground characteristics such as elevation remotely. However, the LIDAR system used land elevation that did not account for long-term subsidence, which is the raising or sinking of land below average land elevation due to such factors as tectonics or aquifer mining. The model showed significant damage to rail and road infrastructure if sea levels rose by 1.4 meters, especially in San Mateo and Alameda counties (Herberger et al. 2011).

Sea level rise may also impact port drainage systems. Port drainage systems could be overwhelmed by higher water levels and more recurrent flooding. If the drainage systems fail on the port property, or in areas surrounding the port, water may stagnate on the terminal and interfere with port operations or damage goods stored on the Terminal.

### **Inadequate Bridge Clearance**

Sea level rise may interfere with ships' bridge clearance and increase port susceptibility to storm surges from hurricanes. Because water levels will rise with time while the bridges remain static, clearance issues may become an issue in ports where bridges are relatively low. The rise in sea level could reduce the top clearance between ships and bridges. One study in California noted that sea-level rise can reduce bridge clearance, thereby reducing the size of ships able to pass or restricting their movements to times of low tide. Bridge clearance may be an issue for boats accessing the Garden City Terminal in the Port of Savannah. Titus (2003) states that bridge clearance is less like to be a problem for small vessels passing under large bridges than for smaller vessels at smaller bridges because bridges outside of large ports are built with very high spans. However, there are instances of bridge heights limiting access to ports. The Bayonne Bridge outside of the Port Newark in New Jersey allows an air draft of 151 feet and has been cited as a limiting factor in receiving some post-Panamax ships (Conway, CRE, & MAI, 2012). Increasing ship size and sea level rise may exacerbate the problem.

### Increased Water Draft

The corollary of decreased air draft is increased water draft as sea level rise marginally deepens channels. However, the effect of slightly deeper channels is not expected to be significant because of its small size compared with overall vessel size (Titus 2003).

### Decreased Port Operations and Efficiency

Sea level rise may also impact port operations and efficiency. Docks and piers built above the water will be closer to the water due to higher sea levels (California Coastal Commission 2001). Higher seas may cause ships to sit higher at the dock and cargo-handling facilities which could affect the loading and unloading of ships, and possibly result in less efficient port operations (Heberger et al. 2011). The horizontal elements of ports, including the decking of wharves, docks, and piers, will be exposed more frequently to uplift forces larger than those occurring now as a result of heightened sea levels (California Coastal Commission 2001). Furthermore, existing infrastructure with a long design life may eventually have to be raised, and new infrastructure may have to be built to higher standards to accommodate sea level rise. According to a 2008 report released by the U.S. Transportation Research Board, “sea level with respect to dock level is an important consideration at both wet and dry docks, general cargo docks, and container berths for clearance of dock cranes and other structures. Changes due to increased intense precipitation and sea level rise could require some retrofitting of facilities. At a minimum, they are likely to result in increased weather-related delays and periodic interruption of shipping services.” (TRB 2008).

Moreover, thunderstorms and hurricanes already suspend port operations on occasion, which could increase due to sea level rise (Ng et al. 2013). If sea level rise exacerbates coastal flooding or storm surge effects, movement within the port may become difficult and goods stored in the port terminal may be more susceptible to flood damage (Wright 2013).

Additionally, increased sea level rise will mean that the elevation at which waves affect structures will increase, potentially undermining the structures per se and will increase the exposure of decks on docks and piers (Nurse-Bray et al. 2013). This could increase corrosion rates and material degradation. In a recent survey of port administrators, it was reported that sea level rise would change port infrastructure maintenance practices. For example, sea level rise would result in “higher salt-water splash zones” requiring more anti-corrosive paint. Paint and paving operations are expensive, yet routine, operations at ports.

Finally, ports should also consider sea level rise’s impact on the depth of water channels. Sea level rise may require additional dredging in the port area because of increased erosion around the port that will affect the depth of the navigable channels (Wright 2013). Thus, research points to different effects on water depth. Sea level rise would appear to automatically increase water depth in channels, but changes in water flow, erosion, and silt deposit make it harder to predict sea level rise’s effects on channel depths in general.



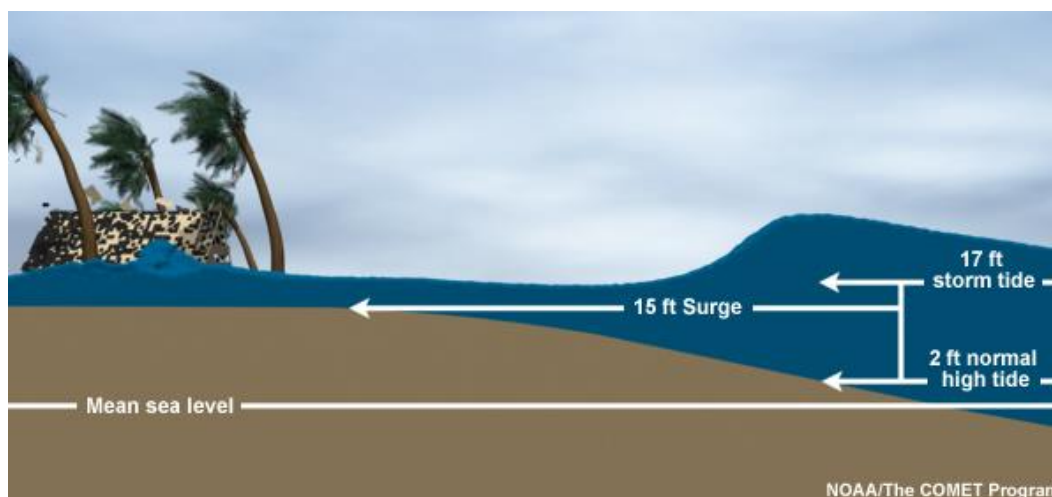
### Salt Water Intrusion

Sea level rise has also been shown in models and observation to push the saltwater and freshwater dividing line upstream in rivers (Bhuiyan & Dutta 2012) and to increase saltwater intrusion into groundwater (Chang et al. 2011). Salt water in rivers is likely to have several effects on ports and channels leading to ports. According to Titus (2003), salt water in rivers can change sediment deposits and change patterns of shoal creation. If saltwater reaches wooden piers or piles, it may also make them vulnerable to marine borers, a set of mollusks or crustaceans that digest wood (Marine Board 1987).

### Storm Vulnerability

There is wide consensus that storms may become more intense due to climate change, and some models indicate increased frequency as well. As far back as 1987, the Marine Board suggested that the increase in the frequency and severity of storms may pose a larger threat to ports than sea level rise alone. Sea level rise will increase port's vulnerability to storm-related flooding even without increases in storm frequency or intensity. Some climate change models predict a decrease in global average hurricane frequency of between 6% and 34% even while average global intensity is projected to increase between 2% and 11% (Knutson et al. 2010). Likewise, the correlation between ocean surface temperature and storm intensity also suggests increasingly destructive storms along coasts (Emanuel 2005), and new satellite data analyzed by Emanuel suggests that both hurricane intensity and frequency may increase with climate change (Massey & ClimateWire 2013). Models by researchers at the University of Copenhagen have predicted up to a 1,000% increase in hurricane frequency if the climate warms by 2 degrees Celsius. When combined with higher sea levels, ports will be especially vulnerable. Depending on facilities' design life, higher sea levels and storm threats can be built into periodic port reconstructions because of the length of time required for significant sea level rise and warming (Titus 2003). However, ports will likely remain vulnerable to economic disruption due to storms and associated storm surge.

Storm surge is an abnormally high series of waves caused by the low pressure and wind in a hurricane which, according to the National Oceanic and Atmospheric Administration, constitute the biggest single threat in hurricanes (National Weather Service). Different factors influence storm surge strength, including the slope of the continental shelf and contours of the sea or river bed, the coast's shape, and the existence of natural or manmade barriers (National Weather Service; Georgia Emergency Management Agency 2013). Storm tide refers to the observed height of water, which includes storm surge and lunar tides (Georgia Emergency Management Agency 2013). Figure 3 below shows the relationship between storm surge, tide, and storm tide.



**Figure 3: Diagram of storm surge and storm tide**

*Source: National Hurricane Center 2011*

Even with preparations, hurricanes and accompanying storm surge can be economically devastating to ports. For instance, Hurricane Katrina destroyed one third of the Port of New Orleans. The port traffic recovered faster than many expected, with the first ship two weeks after the storm, but recovery was still slow. The Port of New Orleans reached half capacity three and a half months after the storm and would not reach full capacity until much later (Sayre 2006). One of the challenges is in finding labor, whose homes were affected by storms, including truck drivers and stevedores (Sayre 2006). When Hurricane Katrina hit the Gulfport Port in Mississippi in 2005, the 7 meter storm surge knocked down container cranes, blew apart storage sheds, and pushed barges hundreds of feet inland (Wright 2013). Even after five years and over \$250 million in new investments, the Gulfport Port was still only operating at 80% of its pre-Katrina capacity (Wright 2013). In 2012 Hurricane Sandy shut down the New York-New Jersey container port for a week, resulting in economic damages that are estimated to reach \$50 billion once all costs are fully calculated (Becker et al. 2013).

### Port Planning: Are Ports Planning for Sea Level Rise?

Port planning has difficulty accounting for climate change issues. Ports typically plan for short-term returns, not for conditions that could occur several years or decades into the future (Becker et al. 2013). Because ports operate on short planning horizons (typically 5 to 10 years), they tend to not account for climate estimates made on 80 to 90 year horizons. As noted previously, sea level rise projections are typically long-term projections, extending out 90-100 years into the future. Despite the mismatched time frames, climate change might still affect the port outside of its planning window since most infrastructure lasts between forty (40) and fifty (50) years.

A survey of port administrators found that few ports are planning projects to increase protection from increased storm activity or SLR and are still using current 100-year storm standards (Becker et al.). The survey showed that ports were more concerned with mitigation issues rather than adaptation issues. Thirty-eight percent (38%) of port administrators expected a SLR of .5-1 m by 2100 and 15% expected more than 1 m.

Thirty-nine percent (39%) of the administrators felt that a 0.5-1 m would be problematic and 58% felt that 1-2 m would be problematic for their port (Becker et al. 2013).

The costs of protecting or retrofitting port property will likely be significant, especially if ports have not prepared for sea level rise and are making ad hoc adjustments as they become apparent rather than strategically adapting their infrastructure based on a long-range plan. The large infrastructure in ports, including cranes, gantries, warehouses, and the like represent capital investments worth significant sums of money. It may be possible for ports to minimize costs associated with sea level rise through decisions in planning, budgeting, and designing future facilities.

## Garden City Terminal

The project team has concentrated its analysis on the impacts of sea level rise to the Garden City Terminal near Garden City, Georgia, and the direct, indirect, and induced economic impacts at the port and through the rest of the port's economic network. The project team has also applied previous research on sea level rise impacts to Garden City Terminal operations to estimate sea level rise's impact on State GDP and output.

## Container Shipping

Much of the recent shipping growth has occurred in Asia. Indeed, 14 of the world's twenty largest container ports are in Asia. Much of this growth has been driven by containerized trade between northeast Asia and the United States, which has resulted in large ports on America's East and West Coasts to handling shipments. Georgia produces many exports of paper, clay, chickens, and other commodities that go to market in Europe, Asia, or elsewhere by sea. As such, the Port of Savannah has grown into the fourth largest container port in the U.S. and the second largest on the east coast behind New York-New Jersey (Hoel et al. 2011).

The Georgia Ports Authority owns and operates eight terminals in the State of Georgia. These terminals are located in four ports: two deepwater ports and two inland ports. The inland ports, Port of Bainbridge and Port of Columbus, house one terminal each. The two deepwater ports, Port of Brunswick and Port of Savannah, each house multiple terminals.

The Port of Brunswick is comprised of four terminals, Colonel's Island RoRo Terminal, Colonel's Island Agri-bulk Terminal, Mayor's Point Terminal, and Marine Port Terminal. These terminals handle breakbulk, agricultural products, and roll-on roll-off vehicles.

The Port of Savannah is comprised of two terminals: the Ocean Terminal and the Garden City Terminal. The Ocean Terminal handles breakbulk cargo next to downtown Savannah and the Garden City Terminal, the authority's largest facility and the location of the authority's headquarters, is "GPA's high-speed container terminal" (GDOT 2011). This section will focus solely on the Garden City Terminal.

## Garden City Terminal Port Operations

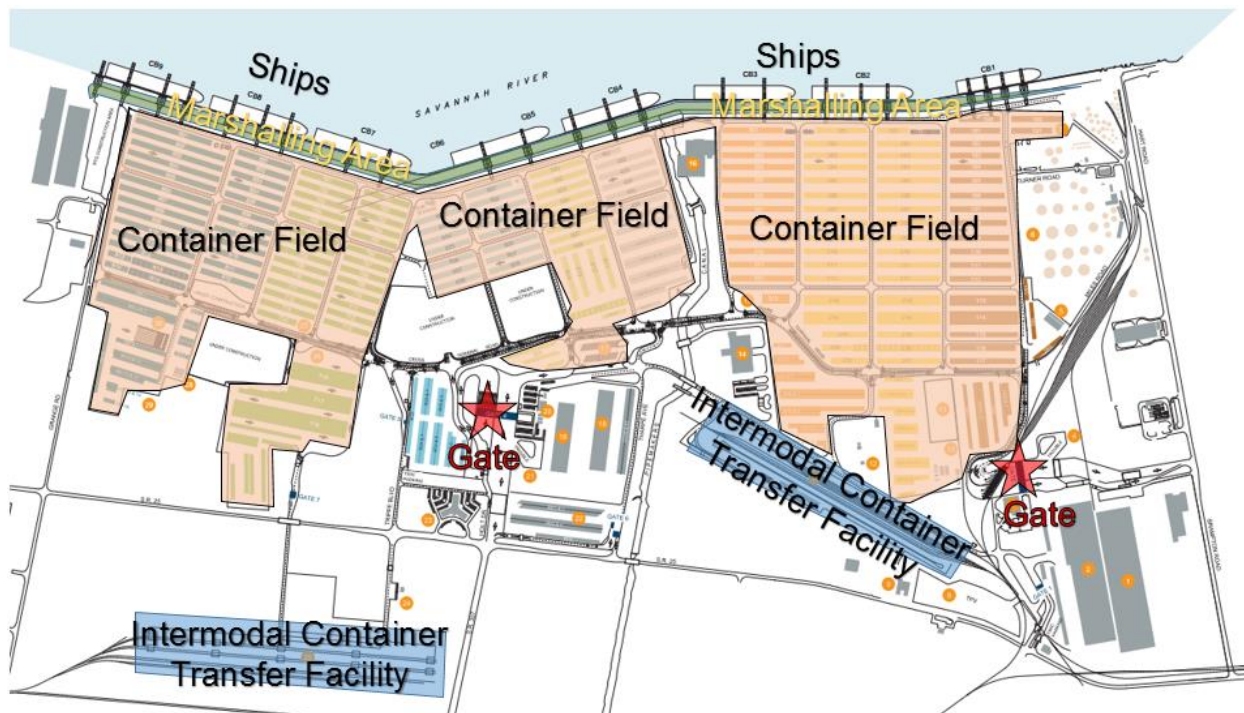
The Garden City Terminal's primary purpose is to transfer containers from ocean vessels to trucks or rail for further shipping, or to receive containers from trucks or railroad operators for transfer to ship. However, organizing, inspecting, cooling, and storing the containers between their inbound and outbound movements requires several specialized areas and equipment to transfer containers among them. Some of the key pieces of equipment are the following.

- Container cranes: Load and unload containers from the ships.
- Rubber-tired gantry cranes: Stack containers in the container field for storage.
- Jockey trucks: Haul the containers among the marshalling area, the container field, the intermodal container transfer facility, and other areas on the port.

- Drayage trucks: Carry containers to and from nearby off-site facilities, including surrounding warehouses.

The Garden City Terminal has several primary functional areas through which containers pass, which are visible in the diagram in Figure 4.

- Marshalling area: The small area adjacent to the ship in which containers are transferred between the gantry crane and jockey trucks (Wong and Kozan, 2010).
- Container field: Flat, paved area in which containers are stacked in rows for temporary storage. They may have electrical outlets to maintain refrigerated containers at the appropriate temperature.
- Gates: Physical checkpoints through which trucks enter and leave the facility.
- Intermodal container transfer facility (ICTF): Areas where containers are transferred between trucks and trains.



**Figure 4: Garden City Terminal Facility Map**

*Source: Georgia Ports Authority*

The project team observed container movement at the Garden City Terminal, which was explained by a Georgia Ports Authority official. Moreover, Wong and Kozan (2010) explain container movements between the ship and container field in view of providing methods to increase jockey truck movement efficiencies.

Trucks with containers enter the Garden City Terminal through gates 3 or 4. Each gate provides a 'trouble' location for diverted trucks directly in front of the gate. After the trucks pass the gate, the containers are unloaded and stacked in the container field to



await transfer to ship. Containers arriving by train are loaded directly onto jockey trucks and driven to the container field if the ship is not there for loading. Both of the terminal's intermodal container transfer facilities are located on-site. Figure 5 depicts a container field serviced by a rubber-tired gantry crane.



**Figure 5: A rubber-tired gantry crane moves a forty foot container in the container field**

Jockey trucks move containers from the container field to the marshalling area, which is a narrow lane directly adjacent to the ship in which containers are loaded and offloaded (Figure 6, Figure 7, and Figure 8). Container cranes attach to holes on the containers' four and lift the container off the trailer chassis and into a container slot in the ship. Heavier containers are normally loaded lowest on the ship to improve stability.



**Figure 6: Jockey trucks preparing to unload in the marshalling area**



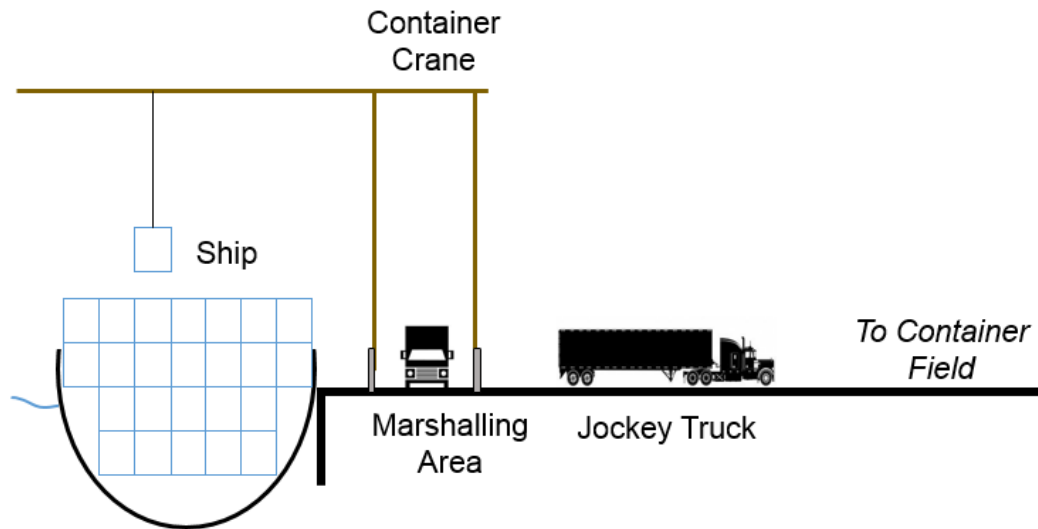
**Figure 7: Container cranes above a container ship**



**Figure 8: A container crane preparing to stack a container on board a ship**

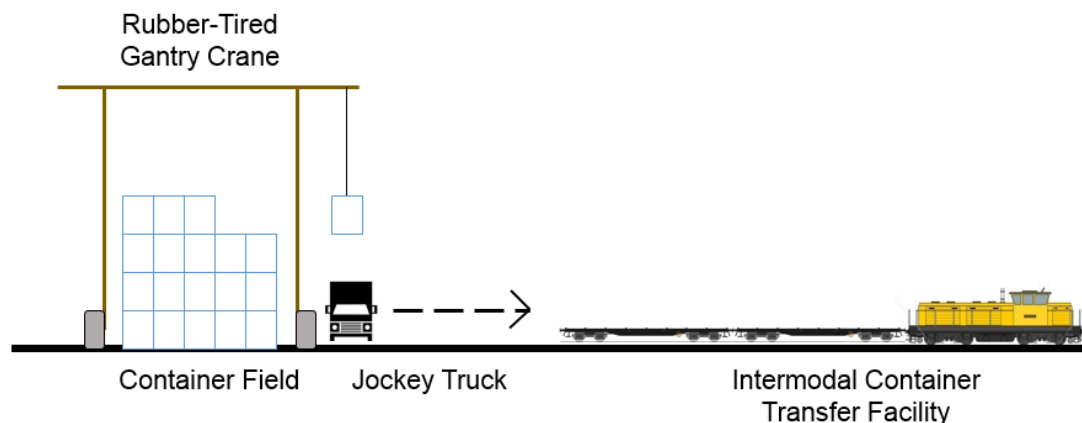
Containers arriving on ships follow a similar process. The container cranes lift containers out of the ship and load them one at a time onto jockey trucks, which drive them to the storage area. Toplifts raise the container off of the jockey truck and deposit into a container high that may be up to seven containers high. There is a storage area where reefers (i.e., refrigerated containers) may be connected to electricity to maintain their cooling units. According to a Georgia Ports Authority representative, containers remain in the storage area for up to approximately seven days depending on agreements with the ocean carrier. They may be charged storage fees called demurrage after the agreed length of time. Eventually, the container are either transferred to trucks for shipment out of the port. Drayage trucks will carry containers on short hauls, such as to adjacent warehouses, or other trucks may carry the containers longer distances. Conversely, a jockey truck moves containers bound for the railroad to

one of the intermodal container transfer facilities for loading onto one of the trains. Figure 8 and Figure 9 below depict the steps in terminal container movement.



**Figure 9: Container movement between the ship and the container field**

*Source: Modified from Wong and Kozan, 2010*



**Figure 10: Container movement between the container field and the intermodal container transfer facility**

*Source: Modified from Wong and Kozan, 2010*

### Specifications/Equipment

The Garden City Terminal spans over 1,200 acres along the Savannah River, inland of downtown Savannah (GPA 2013b). The shipping channel to the terminal is 500 feet wide and ranges from 42 feet deep at mean low water to 49.5 feet deep at mean high water. The lowest vertical bridge clearance along the channel is 185 feet at mean high water and the horizontal bridge clearance is unrestricted. The channel's turning basin, the King's Island Turning Basin, is located next to the terminal and is 1,500 feet by 1,600 feet (GPA 2013b).



The Garden City Terminal has nine container ship berths that total 9,693 linear feet of docking space. The channel depth at each of these container berths varies. Five are 42 feet deep at mean low water and four are 48 feet deep at mean low water. For all container berths, the dock is 15 feet above the mean low water line and 7.5 feet above the mean high water line (GPA 2013b). Figure 11 shows a section of the berth from near water level.



**Figure 11: Ships lined up at dock at Garden City Terminal**

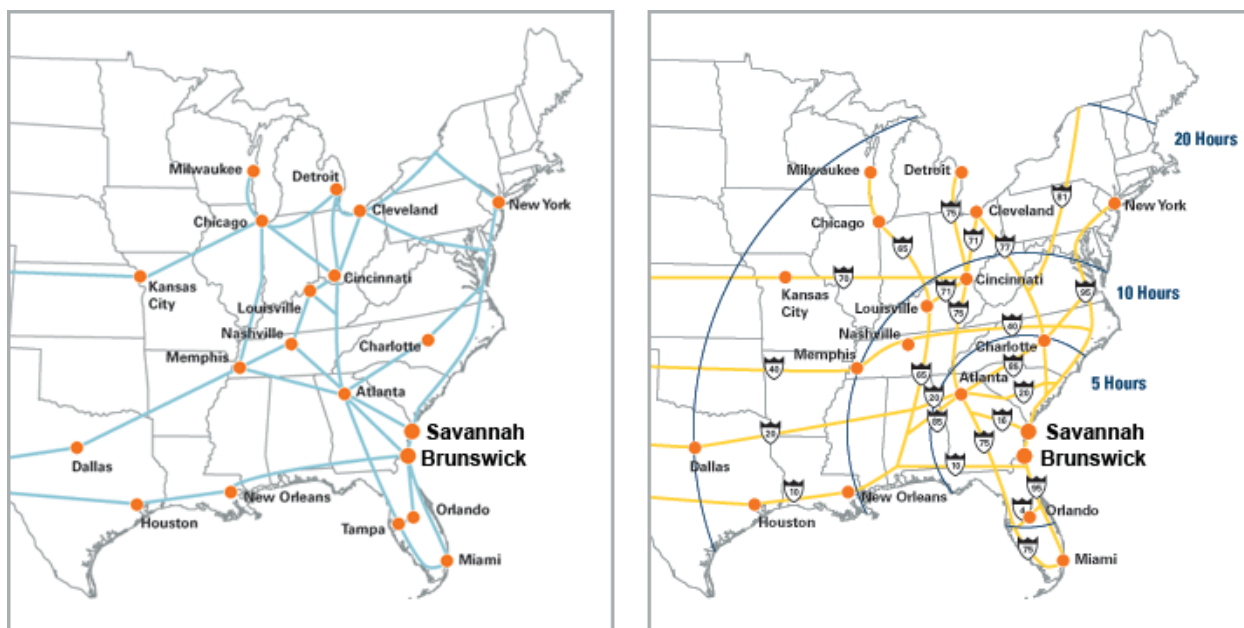
The Terminal also contains many facilities for the storage, handling, and transportation of containers on land. On site, there are 44 reefer racks with electrical hookups that have a capacity of 1,056 slots for refrigerated cargo (GPA 2013b). There are also paved container fields adjacent to each of the container berths that total 432.9 acres of paved area for the storage of containers. Additionally, the terminal houses a rapid dispatch facility that contains an extra 12 acres of paved area for storage (GPA 2013b).

As for equipment, the Georgia Ports Authority (2012) reports on its website that the terminal has 96 total rubber tire gantries, 24 five-high loaded toplifts, 6 four-high loaded toplifts, 16 seven-high empty stackers, and 48 forklifts, all equipment used for lifting and stacking containers on land. Although the website identifies only 23 container cranes (which transfer containers from ships to jockey trucks) an official with the GPA informed the study team that the terminal currently houses 27 container cranes and is planning on selling two smaller cranes and acquiring 10 additional cranes at a cost of \$12 million apiece.

The Garden City Terminal maintains a competitive edge through its access to a robust network of transportation facilities. The terminal is served by two Class I railroads at its two intermodal container transfer facilities (ICTF): the Mason ICTF and the Chatham ICTF. The Mason ICTF has six working tracks and 3 storage tracks of 2,500 feet each and is operated by CSX (GPA 2013b). The Chatham ICTF has 3 working tracks just over 2,000 feet each and a storage track of 12,406 feet and is operated by Norfolk Southern (GPA 2013b). This railroad access connects the Garden City Terminal to

major transportation hubs and population centers in the Southeast, Gulf Coast, and Midwest within a two to three day travel time (GPA 2012). Figure 12a shows the railroad network accessible from the Garden City Terminal.

The Garden City Terminal also boasts a close proximity to two Interstates. Interstate 95, the north-south link along the U.S. East Coast, is within 5.6 miles of the Terminal and Interstate 16, which runs east-west and connects with Interstate 75 in Macon, is only 6.4 miles from the terminal (GPA 2012). Figure 12b depicts the Interstate network accessible by the Garden City Terminal and the major U.S. cities that can be reached within 5, 10, and 20 hours of the terminal via truck.



**Figure 12: (a) (left) rail network accessible from terminal (b) (right) interstate network accessible from terminal (GPA 2012)**

### Current Container Volumes

The leading exports by loaded TEUs for the Port of Savannah, which includes both the Garden City Terminal and the Ocean Terminal, are wood pulp, food, paper and paperboard, clay, and automotive commodities (GPA 2013a). The leading imports at the Port of Savannah are furniture, retail consumer goods, machinery, automotive items, and hardware/houseware (GPA, 2013). Exports from the Port of Savannah are most commonly destined for Northeast Asia, the Mediterranean, Southeast Asia, North Europe, and the Middle East (GPA 2013a). The imports into the Port most often originate in Northeast Asia, Southeast Asia, the Mediterranean, North Europe, and Southern Asia/India (GPA 2013a).

### Future Container Volumes

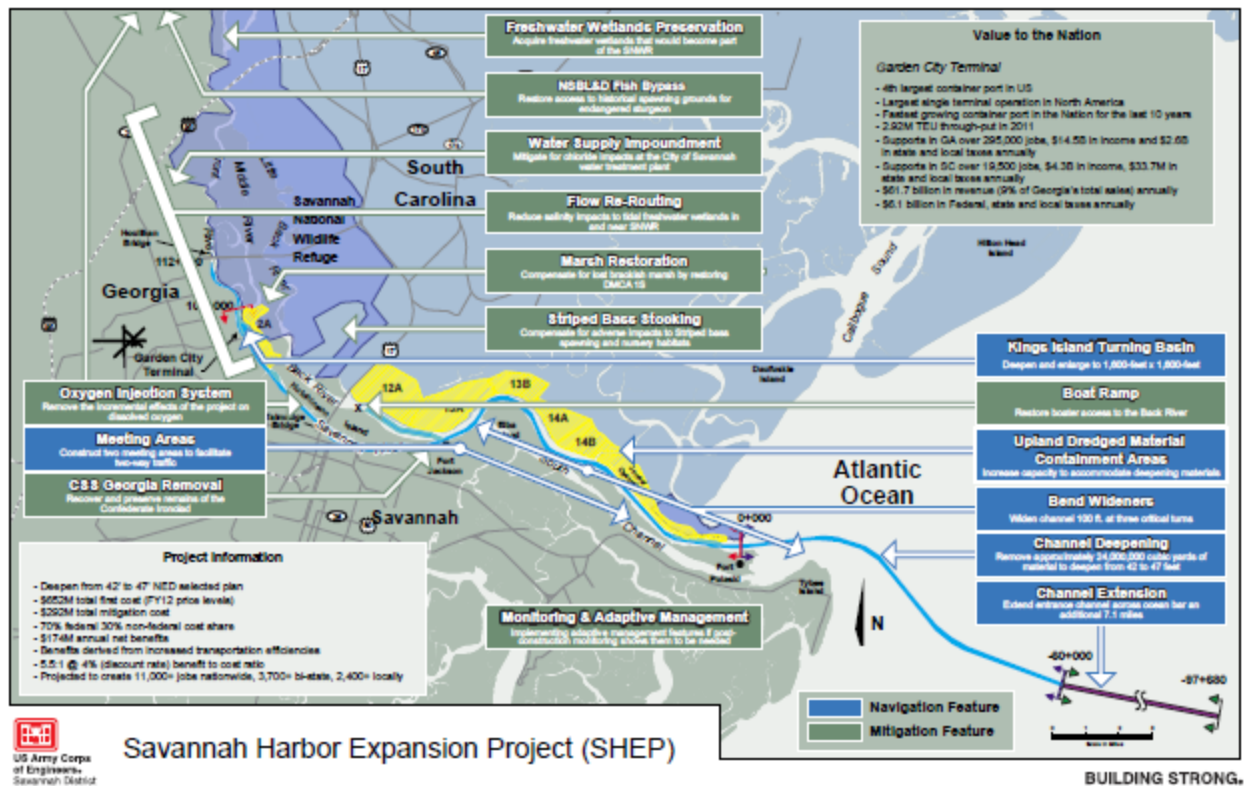
Georgia Ports Authority is planning on container volume increases at the Garden City Terminal of between 5% and 7% over its 10-year planning horizon (U.S. Army Corps of Engineers 2012, Appendix O). The Georgia Ports Authority is considering expansions to

the terminal to accommodate the additional volume. One of its initiatives is to increase its existing space's productivity by increasing storage capacity from 3,512 TEUs per acre per year to 5,500 TEUs per acre per year through a variety of facility and operational improvements. It is also considering expanding its container processing facilities into adjacent properties. Improvements may allow the port to handle 3.85 million TEUs by 2019, which will be sufficient for future operations depending on the rate of container traffic growth. At a rate of 5% annual container growth, the port would still reach capacity by 2023, and with 7% growth capacity would be sufficient until only 2017 (U.S. Army Corps of Engineers 2012). Growth projections appear reasonable based on recent traffic figures. In April 2013, the port moved 258,951 TEUs, which was 4% more than the previous year (GPA 2013b).

### The Savannah Harbor Expansion Project (SHEP)

The Savannah Harbor Expansion Project (SHEP) is a multimillion dollar, multiple-phase expansion project on the Savannah River. In 1999, Congress authorized the expansion project in the Water Resources Development Act of 1999 (Public Law 106-53, Section 102(b)(9)). Under the Act, the Army Corps of Engineers is authorized to deepen the Entrance Channel of the Savannah River to Garden City Terminal from forty-two (42) feet, its current depth, to forty-eight (48) feet to accommodate the large container ships expected after the expansion of the Panama Canal in 2014. According to the Army Corps of Engineers' final report on the expansion project, the Army Corps has recommended deepening the Savannah River to 47 feet (USACE 2012). The U.S. Army Corps has estimated that the annual transportation cost savings from the expansion project will be \$213 million per year (USACE 2012). A deeper shipping channel allows larger and fewer ships to move the same amount of goods at a lower transportation cost. To illustrate this cost savings, container ships currently using the Garden City Terminal on the Savannah River carry on average 5,000 twenty-foot equivalent units (TEUs) (GPA 2013). Once the SHEP is completed and the river is deepened to 47 feet, ships carrying 12,000 TEUs will be able to access the Garden City Terminal (GPA 2013). Moreover, a deeper channel means that larger ships can enter and leave the harbor with less delay in waiting for high tides (USACE 2012).

In addition to deepening a portion the Savannah River leading to the Garden City Terminal, the Army Corps is considering widening the Entrance Channel to create meeting areas at Long Island and Oglethorpe Ranges, widening and deepening of the Kings Island Turning Basin, and widening the channel at three bends in the Savannah River (USACE 2012). Figure 13 illustrates the U.S. Army Corps of Engineers SHEP proposal.



**Figure 13: Savannah Harbor Expansion Project (SHEP)**

Source: U.S. Army Corps of Engineers

The “first cost” for construction of SHEP is estimated at \$652 million, which includes preconstruction engineering and design costs, construction costs and the real estate necessary for the project (USACE 2012). On October 23, 2013, the U.S. House of Representatives authorized funding for the Savannah Harbor Expansion Project in the Water Resources Reform and Development Act of 2013 in a 417-3 vote (Bohan 2013). The Act is expected to become law once the Senate and House of Representatives agree to a final bill (the two Houses of Congress passed different versions of the bill) and the President approves. The appropriations bill is crucial for the project to move forward since 70% of the funds for the SHEP project is coming from the federal government. The remaining 30% will be paid by the State of Georgia. Though the expansion project is costly, the U.S. Army Corps of Engineers has estimated that for every \$1 invested in the harbor expansion project, the United States will see approximately \$6 in return (USACE 2012). Moreover, the U.S. Army Corps has estimated that the SHEP will add \$174 million annually to the U.S. economy (USACE 2012). President Obama and the Army Corps of Engineers have deemed the Port of Savannah a “nationally and regionally significant infrastructure project.”

In 2010, the Savannah District, U.S. Army Corps of Engineers published its General Reevaluation Report (GRR) and Environmental Impact Statement (EIS) in the Federal Register and circulated for review and comment (USACE 2012). The studies evaluated the engineering, environmental, and economic acceptability of various alternatives for the present and future harbor conditions over a 50-year analysis period. (USACE 2010).

In its final GRR, the USACE briefly discussed sea level rise, noting that “[s]ea level rise uncertainty results in a minor level of risk.” (USACE 2012). The Corps stated in its report that “[s]tructural features such as sills or plugs . . . carry minimal risk from sea-level rise uncertainty.” (USACE 2012). It also noted that a “structure’s effectiveness could be reduced slightly with greater than projected sea-level rise rates, but this could be readily addressed through adaptive management of the mitigation features.” (USACE 2012). Moreover the U.S. Army Corps has recommended several mitigation strategies to combat the potential environmental effects of the harbor deepening project: preservation of 2,245 acres of freshwater wetlands; restoration of 28 acres of brackish marsh; construction of a fish bypass around the New Savannah Bluff Lock and Dam near Augusta, Georgia; installation, operation, and maintenance of oxygen injection systems at three locations in the lower Savannah River; construction of boat ramp on Hutchinson Island; construction of a raw water impoundment for water withdrawn from Abercorn Creek by the City of Savannah; and data recovery, removal and conservation of the remains of the CSS Georgia. (USACE 2010).

The SHEP has been embroiled in litigation since its proposal. Opponents to the expansion project have argued that the Corps failed to properly complete its environmental impact statement under the requirements of the National Environmental Policy Act (NEPA) and failed to mitigate potentially detrimental impacts on endangered species and wildlife habitat. Environmental organizations have alleged that harbor dredging will push salt water levels even further upstream, threatening the vitality of valuable tidal freshwater wetlands in the Savannah National Wildlife Refuge. Most recently, several environmental groups filed an injunction action against the U.S. Army Corps of Engineers and others to enjoin the project because the Corps had not applied for a South Carolina environmental permit. The environmental groups and the Army Corps reached a settlement agreement that requires significant environmental mitigation projects and conservation set asides on the part of Georgia, the Army Corps of Engineers and the Georgia Ports Authority (Landers 2013). Specifically, the Georgia Ports Authority has agreed to institute an evergreen fund for dissolved oxygen maintenance for \$2 million over 50 years (Landers 2013). It is estimated that the mitigation costs from the settlement will add an additional \$43 million to the project, most of which will be paid by the Georgia Ports Authority (Landers 2013).

Overall, the SHEP will have significant impacts on the Georgia economy. The deepening and widening of the Savannah River will allow larger ships with more cargo capacity to enter and leave the Port of Savannah. The Port of Savannah is currently investing in capital improvement projects, including crane acquisition and road expansion projects surrounding the Port, to ensure that cargo can be quickly and efficiently transported through port facilities. As discussed above, sea level rise does not appear to be a major factor or concern in the expansion project as the Army Corps feels that any additional rise in sea level can be mitigated with proper engineering strategies.



## Analyzing the Economic Impact of Sea Level Rise at the Garden City Terminal

This section of the report analyzes the economic impact of sea level rise on the Garden City Terminal. The section also addresses the impact of sea level rise on warehouses in Chatham County, employees commuting to and from the port, and regional road and railroad networks along Georgia's coast as impacts to these components will affect economic activity at the Garden City Terminal. First, the study team mapped projected sea level rise at the Garden City Terminal, and looked at how a one meter rise in sea level would affect the equipment, infrastructure and operations at the Garden City Terminal. The study team then extended its scope and identified areas that would be permanently inundated by a one meter rise in sea level, including warehouses in Chatham County, regional road and railroad networks and communities from which Terminal employees commute.

In the second part of its analysis, the study team explored the relationship between storm surge and sea level rise. The team first calculated the economic impact to the State of Georgia of hurricane events at the Garden City Terminal. The economic impact analysis uses economic inputs, such as State gross domestic product (GDP) and economic output attributable to operations at the Terminal, and information on average port recovery times to calculate the loss of economic activity to the State if operations at the Terminal are impaired for various lengths of time. The team then modeled storm surge with and without sea level rise to determine the physical impact of storm surge on warehouses and property in and around the Garden City Terminal. Finally, the study team used its analytical findings and broader information discussed in the literature review section to make recommendations regarding sea level rise preparedness for the Garden City Terminal, Chatham County and coastal Georgia.

### Permanent Inundation from a One Meter Rise in Sea Level

The study team first calculated the degree of permanent inundation at the Garden City Terminal. Our projections indicate that the Terminal is not at significant risk of permanent inundation by a one meter rise in sea level. The team uses "permanent inundation" to denote areas where water will permanently cover normally dry lands. The team differentiates areas that are permanently inundated from areas that will experience "episodic inundation" from storm surge events that are exacerbated by sea level rise. Storm surge events will be discussed in Part II to this section.

### Permanent Inundation at the Garden City Terminal

The study team created a port facilities inundation map using the bathtub model to determine whether a one-meter rise in sea level would affect port operations and physical infrastructure at the Garden City Terminal. The "bathtub model" is normally used to approximate sea level rise based on the assumption of uniform water level rise at all levels of the land being examined. A description of the "bathtub model" is included in Appendix 1. The study team overlaid the one meter sea level rise inundation map created by the previous studio (Keating and Habeeb 2012) on top of satellite imagery of the Garden City Terminal, shown in Figure 14, to examine the extent of impact the projected sea level rise would have on the terminal.



**Figure 14: Inundation of the Garden City Terminal under 1 meter of sea level rise with inundated areas shaded in red**

Figure 14 shows that a projected one meter rise in sea level would have a limited impact on the terminal facilities. While analysis suggests that the wharves themselves will remain above high tide, the storm-water drainage canal that runs through the center of the terminal to the Savannah River is a potential location where water stagnation or drainage-related flooding may occur. Minor flooding indicated in Figure 14 could change maintenance and cargo handling practices at the Terminal. This minor flooding can be properly mitigated for by certain improvements to infrastructure surrounding the canal. The costs of infrastructure improvements to mitigate for the increased sea levels and consequent flooding could be counted as a direct economic impact of sea level at the Terminal.

Assuming the Port does nothing to mitigate for increased sea level, however, permanent inundation around the storm-water drainage canal may erode paved surfaces and require repaving and additional maintenance. Paint and paving are routine, yet expensive, parts of port operations. According to the Georgia Ports Authority, paving and repaving costs represent one of the largest maintenance expenses at the Garden City Terminal (GPA 2013a). Similarly, if the water pools on the

pavement around the canal, this could likewise disrupt movement of cargo around the Terminal as jockey trucks may not be able to move as efficiently on flooded surfaces. Moreover, the flooding along the storm-water drainage canal is close to the Class I CSX rail line. If the rail line is flooded, it could disrupt the cargo movement in and out of the Terminal. Overall, permanent inundation of any portion of the paved area at the Terminal will result in additional expenses for the Georgia Ports Authority.

Finally, the literature has suggested that higher water may also reduce port operations efficiency because ships will sit higher in the water. However, the literature does not specify the means by which higher water levels could degrade efficiency. Details from the Georgia Ports Authority would fill a gap in the literature on port operations and explain any site-specific operational challenges that sea level rise may pose to port efficiency.

### Warehouses in Chatham County

Warehouses are an important part of the ship-to-consumer supply chain. Many Chatham County warehouses receive deliveries from the port that are repackaged and reshipped to inland locations for distribution, sale, or further processing. Thus, warehouses and distribution centers are port-related infrastructure even when they are located off-site.

The study team examined Chatham County warehouses to estimate which warehouses could be directly affected by one meter of sea level rise. The study team isolated parcels in Chatham County with data provided by the Chatham County Board of Assessors. There are 437 warehouse parcels in Chatham County with a concentration located between the Garden City Terminal and the I-95 corridor. While the data does not identify those warehouses with the most operational linkages with the port, the study team's interviews with a warehouse operator and port officials suggest that many warehouse operators locate in Chatham County to handle traffic to and from the Port of Savannah.

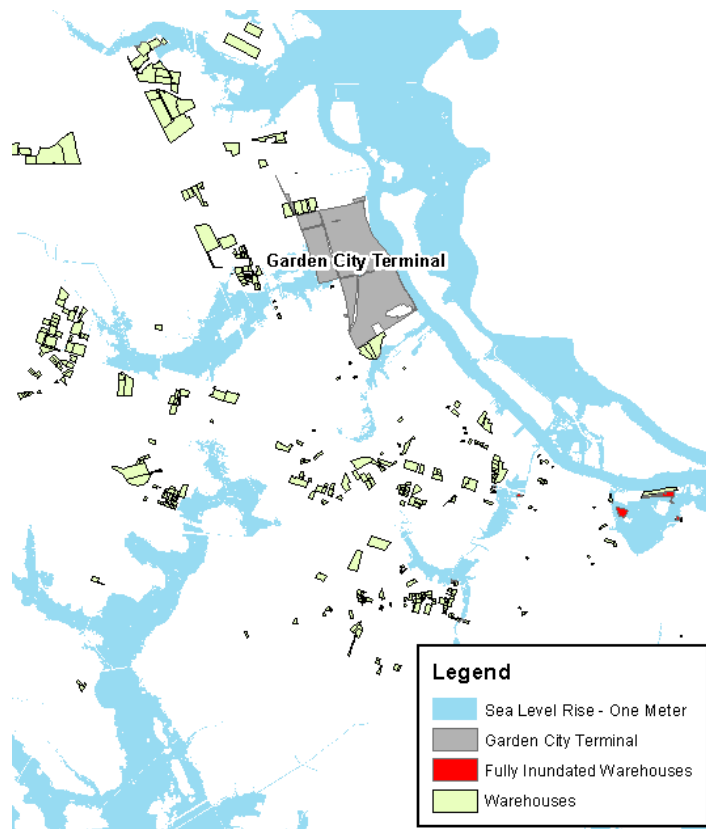
The study team used a spatial selection tool in ArcGIS, described in more detail in Appendix 7, to locate warehouse parcels where a portion of the warehouse area is expected to be flooded by a one meter rise in sea level. There are 28 parcels that may be directly affected by one meter of sea level rise. However, these parcels are on average only 31% inundated, which likely means that they would still be fully or partially operational even with projected sea level rise. Table 2 below shows the building and land value for the portions of the affected parcels, calculated by multiplying the percent of the land area inundated by the entire parcel's value. The results show that approximately 2% of warehouse values are likely to be directly affected by sea level rise.



**Table 2: Warehouse Properties in Chatham County Inundated by One Meter of Sea Level Rise**

	<b>Chatham County Warehouses</b>	<b>At Least Partially Inundated</b>	<b>Fully Inundated</b>	<b>Percentage of Chatham County Warehouses</b>
<b>Number of Parcels</b>	437	28	N/A	N/A
<b>Land Area</b>	2146.52 acres	105.10 acres	32.94 acres	1.50%
<b>Total Building Value</b>	\$896,204,735	\$51,474,247	16,133,367.34	1.80%
<b>Total Land Value</b>	\$167,121,902	\$10,946,053	3,430,777.61	2.10%
<b>Total Assessment</b>	\$425,330,656	\$24,968,120	7,825,657.98	1.80%

Figure 15 shows the location of warehouses in Chatham County, including those that may be partially inundated. Inundation is most likely in warehouses directly adjacent to the Savannah River or on very small sections of property along basins that drain into the river. The large warehouse parcels west and northwest of the port are unaffected by one meter of sea level rise. These parcels include the IKEA warehouse visited by the study team, as well as the adjacent Target distribution center and others whose location makes them advantageous for port-related distribution.



**Figure 15: Warehouses in Chatham County Inundated by One Meter of Sea Level Rise**

## Regional Implications of Sea Level Rise: Employee Commute Patterns and Road and Rail Networks

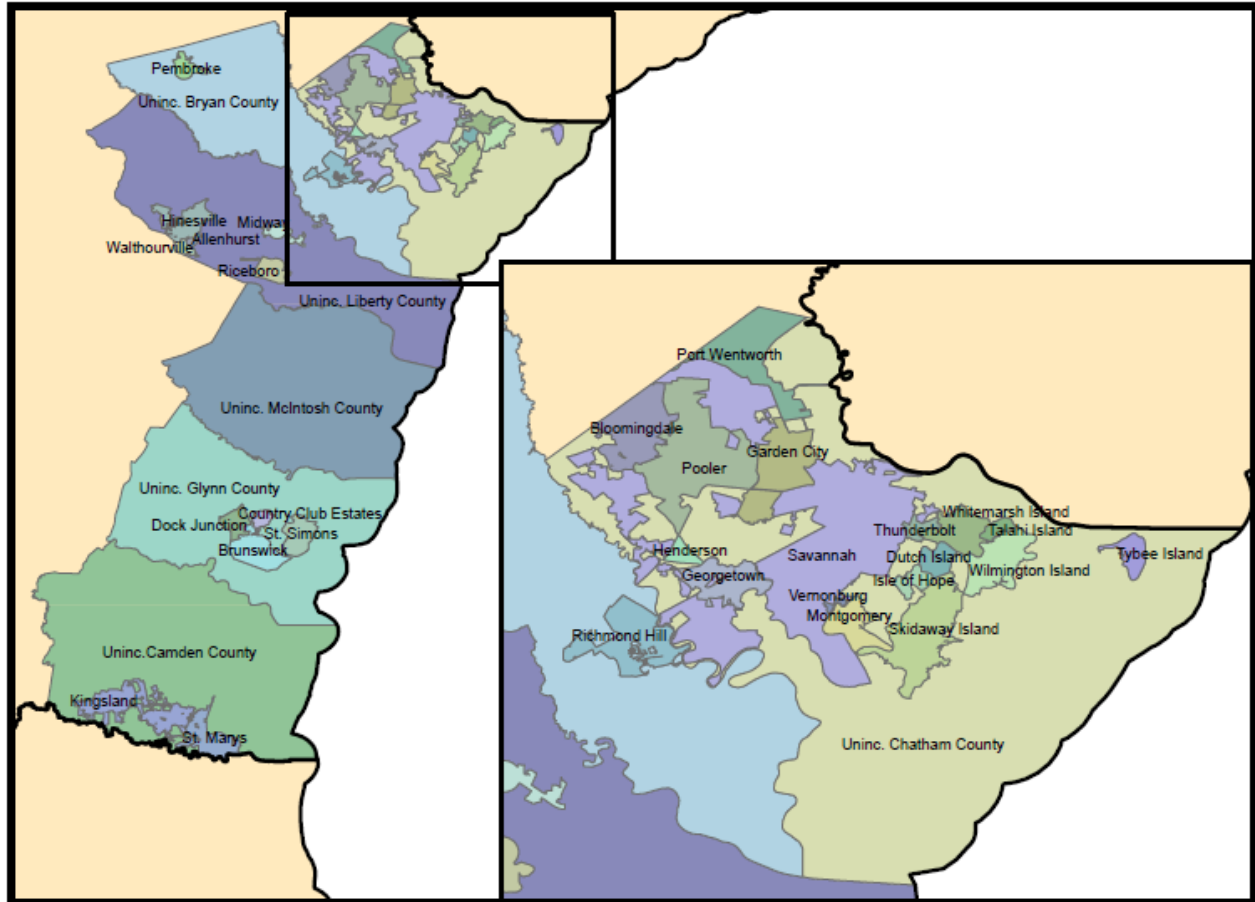
This section analyzes the impact of sea level rise on the Garden City Terminal from a regional perspective. Specifically, the section looks at the impact of a one-meter rise in sea level on regional commute patterns and road and rail networks.

### Regional Commute Patterns

An important asset for the successful operation of the Garden City Terminal is a strong employee base. Although one meter of sea level rise alone had minimal direct impact on the Terminal property and on warehouses, sea level rise in other areas of Georgia can have severe consequences for Terminal operations if Terminal employees reside in areas threatened by rising sea level. This analysis will identify the most prominent locations where Garden City Terminal employees reside, and assess which of those areas are most vulnerable to sea level rise.

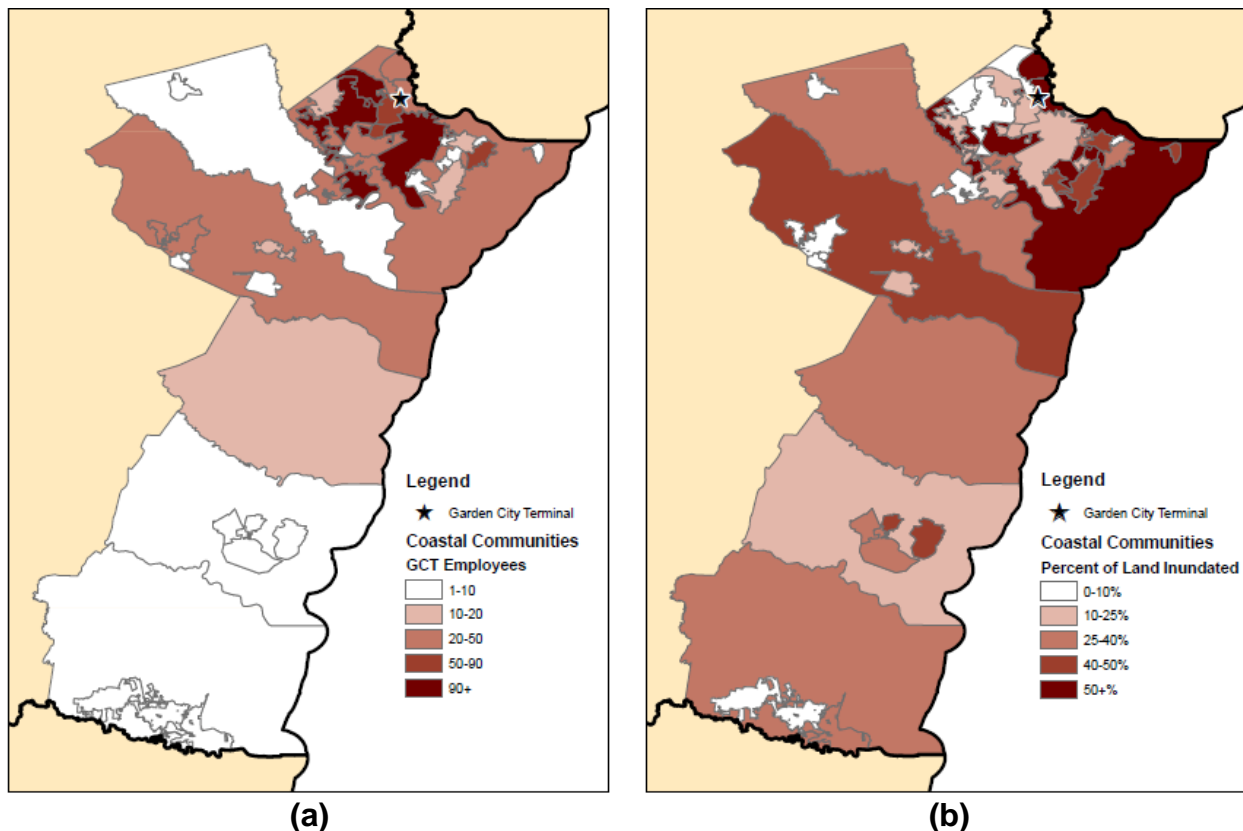
First, the study team examined where Garden City Terminal employees reside. The study team used data from Chatham County's tax assessor office in conjunction with the U.S. Census Bureau's online commuting pattern application, On the Map. Using this web-based application, the team found the cities and unincorporated counties where employees of the Garden City Terminal reside. Next, the study team identified the cities or unincorporated counties that were most vulnerable to sea level rise. The team overlaid inundation maps created by the previous studio (Habeeb and Keating 2012) with cities and unincorporated counties to determine the percentage of land area inundated by sea level rise.

The results of the commuter analysis are presented for the six coastal Georgia counties, although a number of employees come from other states and inland Georgia counties. In the six coastal Georgia counties there are 36 communities, 30 municipalities and the unincorporated area in each of the counties. Figure 16 shows the locations of each of the 36 coastal communities examined in this analysis.



**Figure 16: Map of Coastal Georgia communities**

Below, Figure 17 presents a map of the results for both parts of the commuter analysis. The map to the left, Figure 17a, represents the number of Garden City Terminal employees residing in each of the coastal communities. Communities with a darker shade of red contain a larger number of employees. As is seen in the map, communities in Chatham County contain the majority of employees that commute to Garden City Terminal. However, Terminal employees reside in communities in each of the six counties along Georgia's coast. As is expected, counties further from the Terminal, such as Camden and Glynn, contain fewer employees than counties nearer to the Terminal--McIntosh, Liberty, and Bryan. In Chatham County, the communities that contain the most employees are located further inland and clustered around the Terminal. The map to the right, Figure 17b, shows the vulnerability of coastal communities to sea level rise inundation. The counties are colored based on the portion of the community's land mass that is inundated by a one meter of sea level. The counties colored in darker red are the most vulnerable to sea level rise. The most vulnerable communities are primarily located in Chatham County along the Atlantic coast and the banks of the Savannah and Ogeechee Rivers. In addition to communities along the rivers, communities further inland are generally less vulnerable to inundation than those communities closer to the coast.



**Figure 17: Commuter analysis results. (a) Garden City Terminal employee residences by community. (b) Percent of land inundated by one meter of sea level rise**

Detailed commuter data are included in the tables below. Table 3 is a list of the ten communities with the most Garden City Terminal employees. Table 4 is a list of the ten communities with the highest vulnerability, land area wise, to sea level rise impacts.

Looking at Table 3 and Table 4, Unincorporated Chatham County and Unincorporated Liberty County are popular locations for Garden City Terminal employees to reside and are extremely vulnerable to inundation from rising sea levels. Chatham and Liberty Counties are the only communities to find themselves on the top of both lists for number of Terminal employees and extent of inundation. In addition to Chatham and Liberty counties, Wilmington Island, Georgetown, Savannah, Garden City, Unincorporated McIntosh County, Whitemarsh Island, Skidaway Island, and Montgomery also contain a large number of Terminal employees and will experience significant inundation from sea level rise. While this analysis identifies communities of interest for the Garden City Terminal with respect to sea level rise, data was not available for the analysis to identify the exact number of employees or the locations of employee residences vulnerable to sea level rise.

**Table 3: Top Ten Communities for Garden City Terminal Employee Residence**

	<b>Community</b>	<b>Employees</b>	<b>Percent Inundation</b>
1	Savannah, GA	374	24.2%
2	Pooler, GA	92	1.9%
3	Garden City, GA	64	19.4%
4	Wilmington Island, GA	51	36.4%
5	Hinesville, GA	43	0.0%
6	Georgetown, GA	38	34.3%
7	Unincorporated Chatham County, GA	37	83.9%
8	Port Wentworth, GA	37	9.6%
9	Richmond Hill, GA	37	0.0%
10	Unincorporated Liberty County, GA	30	45.7%

**Table 4: Top Ten Communities with the Highest Percentage of Land Area Inundated by Sea Level Rise**

	<b>Community</b>	<b>Percent Inundation</b>	<b>Employees</b>
1	Unincorporated Chatham County, GA	83.9%	37
2	Dutch Island, GA	61.8%	4
3	St. Simons, GA	48.8%	5
4	Montgomery, GA	45.9%	10
5	Country Club Estates, GA	45.8%	1
6	Unincorporated Liberty County, GA	45.7%	30
7	Skidaway Island, GA	42.8%	11
8	Tybee Island, GA	42.7%	5
9	Whitemarsh Island, GA	41.6%	13
10	Unincorporated McIntosh County, GA	39.4%	17

## The Impact of Sea Level Rise on Regional Transportation Networks: Road and Railroad

This section examines the length of roads and railroads that will be inundated by a one meter rise in sea level. The Garden City Terminal is heavily dependent on the rail and road networks along the coast of Georgia. Sea level rise will have a major impact on these rail and highway connections. The study team assumes that all vital infrastructure inundated by sea level rise will be rebuilt as bridges over the inundated areas due to the economic importance of the facilities. It is important to note that these impacts to the transportation network extend over the nearly 100 planning year horizon and do not necessarily occur at one point in time, since the effects of sea level rise are gradual. It is also important to note that rebuilding these facilities as bridges is only a temporary fix to the issue. Continuing sea level rise past the planning horizon will necessitate further rebuilding of inundated transportation networks.

The analysis for this section is divided into two pieces: the impacts to the road network and the impacts to the railroad network. The major findings of this analysis are as follows:

- 22.59 miles of major roads will likely be inundated under one meter of sea level rise
- Assuming all inundated major roadway segments are reconstructed as bridges, 336 bridges at a total cost of \$350-922 million will need to be constructed.
- 14.04 miles of railroads will likely be inundated under one meter of sea level rise.

### Road Network

The study team began its analysis of sea level rise's impact on the road network by using the functional classification system used by Georgia Department of Transportation (GDOT) and Federal Highway Administration (FHWA) to determine the most important roads along Georgia's coast. The functional classification system divides roads into one of a number of categories: interstates, highways, other freeways and expressways, principal arterials, minor arterials, major collectors, minor collectors, and local roads. For purposes of this analysis, the study team examined only interstates, other freeways and expressways, and principal and minor arterials because of their traffic volume and regional importance. The study team overlaid the major roads with the inundation map created in the previous studio (Habeeb and Keating 2012) to identify segments that would be inundated based on the functional classification system. Next, the study team calculated the average number of lanes for each of the functional classifications in Georgia from the FHWA Highway Statistics Series (FHWA 2011) and identified the range of minimum shoulder widths and lane widths for each of the functional classifications from the FHWA's Mitigation Strategies for Design Exceptions (FHWA 2007).

Using these figures and the segment lengths, the study team estimated the range of the minimum bridge area for each of the functional classifications of roadways. As noted above, the study team is estimating bridge area because we assume that inundated roads will be rebuilt as bridges over the water. Table 5, Table 6, and Table 7 show the ranges of the minimum shoulder widths, the ranges of lane widths, and the average

number of lanes for each functional classification that were used to calculate the range of the bridge areas that would need to be constructed to adapt to one meter of sea level rise.

**Table 5: Range of minimum shoulder widths by functional classification**  
Source: FHWA 2007

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials
<b>Right Shoulder</b>	10'-12'	4'-12'	2'-8'	2'-8'
<b>Left Shoulder</b>	4'-12'	0'	0'	0'

**Table 6: Range of suggested lane widths by functional classification**  
Source: FHWA 2007

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials
<b>Lane Width</b>	12'	12'	10'-12'	10'-12'

**Table 7: Average number of lane-miles per centerline-mile on Georgia roads by functional classification**  
Source: FHWA 2007

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials
<b>Average Number of Lanes</b>	5.59	4.70	3.43	2.37

Next, the study team applied a per square foot bridge construction cost for each of the road segments that would be inundated with a one-meter rise in sea level. The Florida Department of Transportation (FDOT 2011) publishes a range of bridge construction costs per square foot for bridges of varying lengths and types. FDOT classifies bridges into short span (20'-45'), medium span (45'-150'), and long span (150'). The study team assumed that short span bridges would be simple span bridges with pre-cast concrete slabs and that medium and long bridges would be simple span bridges with concrete decks and pre-stressed girders, as those were the cheapest options. Table 8 displays these construction costs for the varying span lengths.

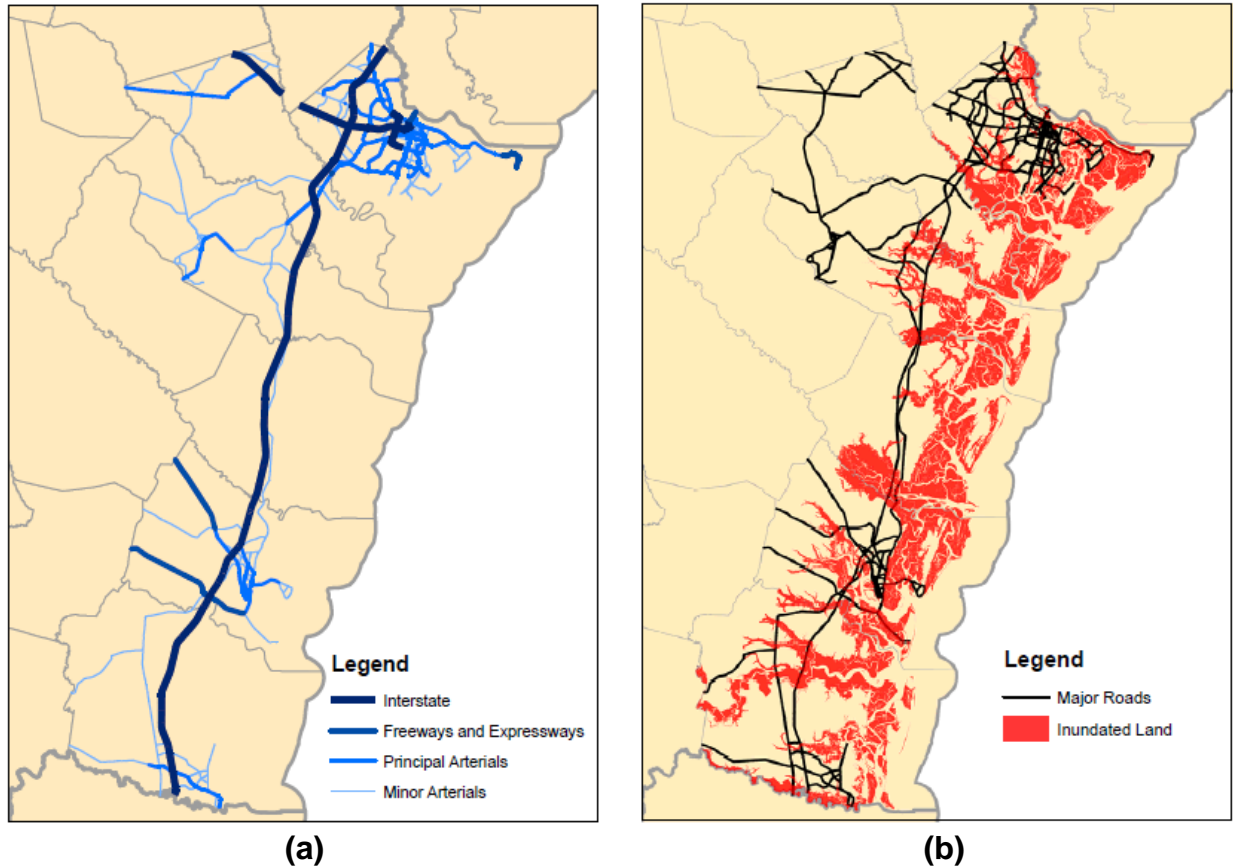


**Table 8: Bridge construction costs per square foot for bridges of varying lengths**  
**Source: FDOT 2011**

Span	Bridge Length	Cost (per sq. ft.)	Type of bridge
Short	20'-45'	\$80-\$150	Pre-cast Concrete Slab Simple Span
Medium	45'-150'	\$67-\$140	Concrete Deck/ Pre-stressed Girder - Simple Span
Long	150'+	\$67-\$140	Concrete Deck/ Pre-stressed Girder - Simple Span

Using these values, the study team found the range of construction costs for each of the segments by applying the appropriate construction costs to the bridge areas. FDOT did not publish information regarding the costs of elevating a section of roadway less than twenty (20) feet long, so the study team applied the short span construction unit costs to spans under twenty (20) feet as well. A more detailed explanation of the study team's methodology for calculating bridge construction costs can be found in Appendix 2.

GIS maps of Georgia's coastal road network are presented in Figure 18. The map on the left shows the road network separated by its functional classification. This map shows that Chatham County and the area surrounding the port have the most robust road network. However, the map also shows that there are roads along the coast, particularly I-16, I-95, and US 17, that are important links to other regions. The map on the right shows the entire network of major roads (interstates, freeways/expressways, and arterials) overlaid with a map of the land expected to be inundated under one meter of sea level rise, according to the bathtub model used in the previous studio (Habeeb and Keating 2012). This map shows that the extensive road network in Chatham County and the critical highway facilities outside of Chatham County are vulnerable to the effects of sea level rise.



**Figure 18: Georgia coast's major road network. (a) Functional classification of major road network. (b) Inundation of major road network under sea level rise**

The geographic analysis of the road network produced a list of the major road segments along the Georgia coast that would be inundated along with the lengths of the segments.

Table 9 shows the number of segments that would be inundated by a one meter rise in sea level, broken down into the categories influenced by FDOT's bridge construction cost guidelines and the functional classification of the road. Table 10 shows the aggregated length of the segments broken down into short and medium/long span and the functional classifications.

**Table 9: Number of roadway segments inundated under one meter of SLR**

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	Total
Short Span (including shorter span bridges) (0'-45')	19	4	37	24	<b>84</b>
Medium/Long Span (45'+)	52	22	111	67	<b>252</b>
<b>Total</b>	<b>71</b>	<b>26</b>	<b>148</b>	<b>91</b>	<b>336</b>

In total, 336 segments of roadway could be impacted by sea level rise. Nearly half of the segments impacted by sea level rise are principal arterials; however, minor arterials and interstates are also largely impacted. For all road classifications, a majority of the segments are longer than 45 feet and will require a medium or long span bridge. Of the 336 roadway segments, only 84 will require a short span bridge whereas 252 will require the construction of a medium or long span bridge.

**Table 10: Length of road network inundated under one meter of SLR (in miles)**

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	Total
Short Span (including shorter span bridges) (0'-45')	0.083	0.011	0.194	0.098	<b>0.386</b>
Medium/Long Span (45'+)	3.701	1.764	12.388	4.351	<b>22.204</b>
<b>Total</b>	<b>3.784</b>	<b>1.775</b>	<b>12.582</b>	<b>4.449</b>	<b>22.589</b>

When considering the length of roadway impacted, the principal arterials still make up the most significant portion of the network impacted. In total, 22.589 miles of the roadway network will be impacted by one meter of sea level rise, and 12.582 of these miles will be on principal arterials. Minor arterials and interstates are also heavily impacted, with 4.449 miles of minor arterials and 3.784 miles of interstates inundated. As is expected, the majority of the length of roadway that will need to be reconstructed will require the construction of a medium or long span bridge to adapt to sea level rise; 22.204 miles of the total 22.589 miles of inundated roadway will be built in the form of medium and long span bridges.

Next, using the number and length of bridges along with the range of road widths and range of bridge construction unit costs, the study team calculated the lower and upper limit of bridge construction costs that would be required to adapt the major road network for a one meter rise of sea level. Table 11 includes the calculated costs broken down by functional classification.

**Table 11: Costs of bridge construction by functional classification to adapt to sea level rise**

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	<b>Total</b>
Low	\$108,933,319	\$37,999,465	\$162,083,152	\$40,429,606	<b>\$349,445,541</b>
High	\$255,027,906	\$89,842,873	\$457,793,114	\$119,462,091	<b>\$922,125,986</b>

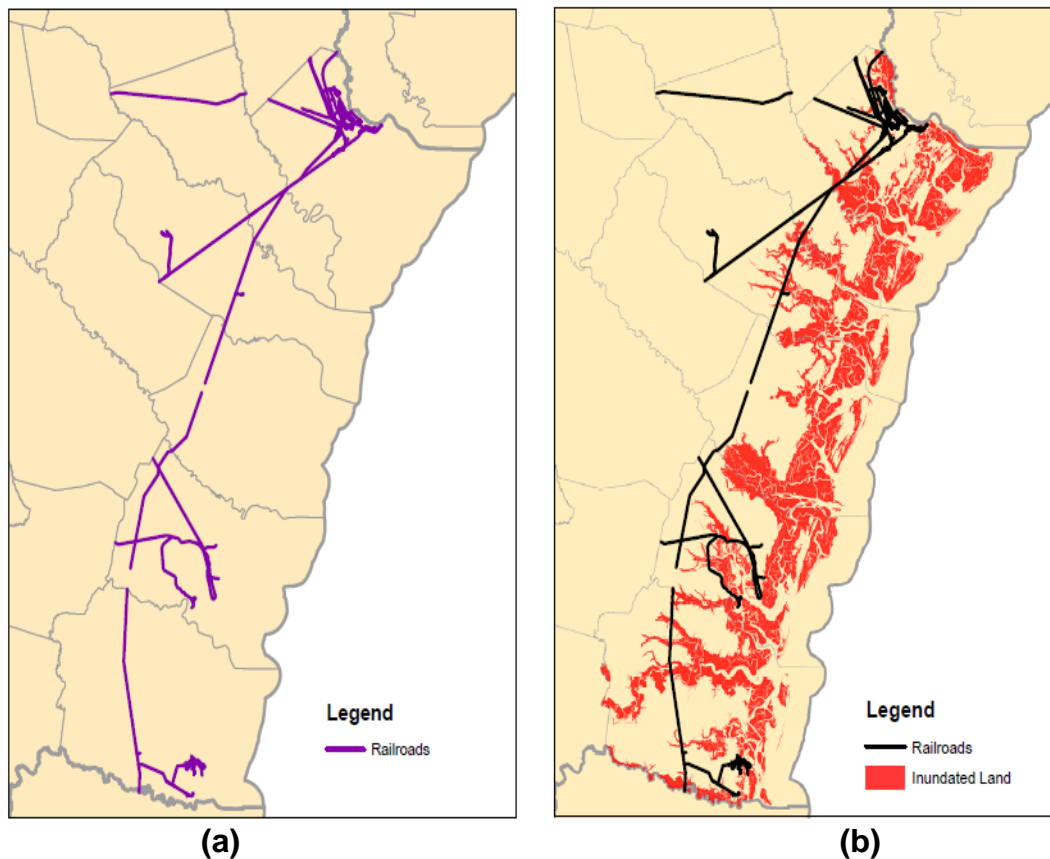
Due to the variations in minimum shoulder width, typical lane width, and bridge construction costs, the expected costs of rebuilding the inundated road segments as bridges varies. The total cost of reconstructing the inundated segments of the roadway network as bridges is expected to be as low as \$349 million and as high as \$922 million, with these costs coming chiefly from interstates and principal arterials. It is important to note that this range of costs assumes current construction costs and the current roadway network. Construction costs are likely to rise and the road network is likely to expand over the study's one-hundred year time horizon, thus making the potential costs even greater than costs calculated in this report. It is also important to note that the gradual nature of sea level rise allows affected communities to plan ahead for sea level changes and to design infrastructure that accommodates such changes. While a strategy of rebuilding inundated roads as bridges will temporarily solve the issues associated with sea level rise, this is not a long term solution. Sea levels will continue to increase past the planning horizon examined in this study.

### Railroad Network

The study team used a GIS shapefile of the nation's railroad system provided by the U.S. Census Bureau to analyze the impact of sea level rise on rail networks in the coastal Georgia region. Only the rail infrastructure in the six county coastal Georgia region was examined in this section. The study team overlaid the sea level rise inundation map created in the previous studio (Habeeb and Keating 2012) on the coastal railroad infrastructure. The study team identified the number of segments and the length of each of the segments expected to be inundated under one meter of sea level rise. The team was not able to find reliable construction costs for railroad bridges. Therefore, the railroad network analysis does not include a calculation of the reconstruction costs for elevating rail networks due to sea level rise.

The GIS maps produced of coastal Georgia's railroad network are presented in Figure 19. The map on the left, (a), depicts the current railroad network. This map indicates that Chatham, Glynn, and Camden counties have the highest concentrations of rail

infrastructure along the coast. However, the map also shows that the other coastal counties contain rail lines that connect the coastal community to other regions in the Southeast, like Florida, South Carolina, and inland Georgia. The map on the right, (b), shows the same railroad network overlaid with a map of the land expected to be inundated with one meter of sea level rise. This map visually depicts the extent railroad infrastructure along Georgia's coast will be affected by a one meter rise in sea level.



**Figure 19: Georgia coast's railroad network. (a) Existing railroad network. (b) Inundation of railroad network under sea level rise**

According to the geographic analysis of the rail network, 84 segments may be inundated as a result of one meter of sea level rise. The length of these segments totals 14,036 miles. Due to the privatized nature of the railroads, the governments on the coast will likely not be responsible for adapting this infrastructure to sea level rise. However, it will be in the best interest of these communities to ensure that these connections are restored. As with the road network, it is important to point out the time horizon on this analysis. Since one meter of sea level rise is not expected until 2100, communities along the coast will be able to gradually adapt the infrastructure over several decades. Additionally, there is potential for further sea level rise after the 2100 planning horizon.



## Storm Surge

### The Relationship between Sea Level Rise and Storm Surge

Storm surge from hurricanes threatens many coastal areas, especially when coupled with the fact that climate change is likely to increase storm intensity. Georgia's westernmost location on a concave Atlantic coastline and good fortune have combined to protect Georgia from direct hurricane strikes since 1989. Still, if there is a future hurricane strike, Georgia's shallow continental shelf and basin-like coastal shape will accentuate the resulting waves, giving Georgia "the potential for the second highest storm tide on the East coast" (Georgia Emergency Management Agency 2013). Waves would not stop at the coast, but could also propagate up the Savannah River to the Garden City Terminal (Naval Research Laboratory 2008). Storm surge threatens to magnify the potential effects of sea level rise. Sea level rise will diminish the amount by which hurricane-driven waves have to rise to temporarily flood land and damage property since higher sea levels provide a higher base for storm surge. The water level associated with any given frequency of coastal storm or hurricane will grow, and communities will see waters reach new heights (Tebaldi et al. 2012). For instance, a "one meter rise in sea level would enable a 15-year storm to flood areas today that are only flooded by 100-year storms" (IPCC 1998). Storm surge levels will depend heavily on hurricane's frequency, size, strength, and path. While Georgia has not had any direct hurricane impacts in the past decades, a historical perspective back to 1800 shows that hurricane impacts are possible and suggests that the absence of hurricanes may be an anomaly rather than an enduring trend. Moreover, if predictions of stronger and potentially more frequent hurricanes accompanying climate change hold true, increased vulnerability to storm surge may represent one of the most significant sea level rise-related dangers to coastal communities.

In this section, the study team used several modeling techniques identified in the literature to assess the storm surge vulnerability with and without sea level rise for Garden City Terminal, Chatham County, and area warehouses. The purpose is to approximate the potential storm surge vulnerability increase due to sea level rise. The analysis does not account for climate change-related variations in storm intensity, but instead focuses on sea level changes alone.

### Economic Impact at Garden City Terminal

The study team conducted an economic impact analysis that calculates the loss of economic activity to the State of Georgia in the event of a hurricane to determine the economic impact of sea level rise from reduced operations at the port. Thunderstorms and hurricanes already suspend port operations on occasion. As noted above, the disruptive effects of these storms on port operations will increase as sea levels rise. Estimation of economic impacts after natural disasters requires two factors: (1) data inventory and (2) an appropriate methodology to analyze available data (Pan 2011). The team was able to locate much of the necessary economic data and information on physical infrastructure for this analysis through prior studies, U.S. Census information, tax parcel data from the Chatham County tax assessor, and from a tour of the facilities and infrastructure in and surrounding the Garden City Terminal. This report primarily

used economic inputs provided by the University of Georgia's 2012 report, "Economic Impact of Georgia's Deepwater Ports," to quantify the economic impact of a one meter of rise in sea level at the Garden City Terminal ("UGA Study").<sup>1</sup>

The study team quantified the impact of sea level rise on the Garden City Terminal in terms of overall output and gross domestic product for the State of Georgia. In addition to output and State GDP, the team also addressed the impact of sea level rise on employment and income, though we did not quantify these estimates. Instead, we qualitatively described the potential effects of sea level rise on employment and income. The team qualitatively described these figures, rather than assigning each a specific cost, because in most instances any loss or disruption to income or employment is temporary and short-term. Port employees are not likely to lose long-term employment opportunities because of sea level rise, and will not likely lose a substantial amount of employment income because of sea level rise. Employment may be impacted in the short-term but the disruptions at the port would probably not cause permanent job loss in the long-term. However, this assumption may fail if the port is shut down for an extended period of time as in the case of the Port of New Orleans or Port of Gulfport after Hurricane Katrina. Since those ports operated at a significantly reduced capacity for several months, port employees (mostly wage-earning employees) left in search of other employment opportunities.

Salaried employees would likely continue to be paid even if the port is shut down. Thus, their income would not be impacted by a temporary port shutdown. A shutdown of the Garden City Terminal may have a larger impact on wage-earning employees (such as owner-operator trucks) because their income is tied to the number of hours worked. However, wage-earning employees would likely be able to make up any lost time and wages once the port resumes operations. Ships that were not able to access the port during a shutdown would use the Garden City Terminal once it reopened.

The study team primarily used economic inputs provided by the University of Georgia's 2012 report, "Economic Impact of Georgia's Deepwater Ports," to quantify the economic impact of a one meter of rise in sea level at the Garden City Terminal ("UGA Study"). The UGA study looked at the economic impact of the Port of Savannah and Port of Brunswick (Georgia's deepwater ports) on Georgia's economy in terms of output, income, GDP, employment and taxes. The UGA study separated economic impact into direct economic impact, indirect economic impact, and induced economic impact. A detailed description of the Study's methodology is found in Appendix 3.

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<sup>1</sup> Every 3-5 years, the University of Georgia's Selig Center for Economic Growth completes a report on the economic impact Georgia's deepwater ports have on the State's economy in terms of output, income, employment and taxes. Georgia's deepwater ports include the Port of Savannah (Garden City Terminal and Ocean City Terminal) and the Port of Brunswick (Colonel's Island Terminal and Mayor's Point Terminal).

## Output and State GDP at the Port of Savannah in 2011

The Garden City Terminal is a major economic engine in the State of Georgia.

- In 2011, the port industry at the Port of Savannah contributed \$1,493,000,000 in *total GDP* to the State of Georgia, which included \$975,000,000 in direct GDP and \$518,000,000 in indirect and induced GDP.
- In 2011, the port industry at the Port of Savannah contributed \$3,043,000 in *total output* to the State of Georgia, which included \$1,983,000 in direct output and \$1,060,000 in indirect and induced output.

Port industry data was specifically identified in the UGA Study. However, data for the port users included economic activity at both the Port of Savannah and Port of Brunswick. In order to extract only Port of Savannah data, the team assumed that the proportion of port *user* output attributed to the Port of Savannah would be identical to the proportion of port *industry* output attributable to the Port of Savannah. This proportion was 78%. Using this figure, the team estimated port user impact on the State economy.

- In 2011, port users at the Port of Savannah contributed \$48,927,275,977 in *total output* to the State of Georgia, which included \$28,518,834,639 in direct output and \$20,435,524,578 in indirect and induced output.

Like the output data, the port user data included economic activity at both the Port of Savannah and Port of Brunswick. In order to extract only Port of Savannah data, the team ran the same calculation for deriving impact to GDP as it did for output. The proportion calculation was approximately 78%. The team therefore assumed port user GDP attributable to the Port of Savannah was 78% of the total port user GDP.

- In 2011, port users at the Port of Savannah contributed \$23,893,480,336 in *total GDP* to the State of Georgia, which includes \$11,794,202,899 in direct impact to GDP and \$12,051,666,667 in indirect and induced impact to GDP.

**Table 12: Output and State GDP at the Port of Savannah, FY 2011**

GPA Annual Economic Impact (\$ Million)	Output			State GDP		
	Direct	Indirect/Induced	Total	Direct	Indirect/Induced	Total
Port Industry (All Ports)	\$ 2,552	\$ 1,363	\$ 3,917	\$ 1,242	\$ 666	\$ 1,907
Port Industry (Port of Savannah)	\$ 1,983	\$ 1,060	\$ 3,043	\$ 975	\$ 518	\$ 1,493
Proportion of Impact Attributed to Savannah	78%	78%	78%	79%	78%	78%
Port Industry	\$36,702	\$26,277	\$62,980	\$15,024	\$15,495	\$30,519
Port Users	\$28,519	\$20,436	\$48,927	\$11,794	\$12,052	\$23,893
Total Impact	\$645	\$455	\$1,099	\$270	\$266	\$537

Source: University of Georgia, Selig Center for Economic Growth, The Economic Impact of Georgia's Deepwater Ports, FY 2011

Next, the team had to determine what percentage of the output and GDP was attributable to the Garden City Terminal since the Port of Savannah information includes economic activity at the Garden City Terminal *and* the Ocean City Terminal. According to the Georgia Ports Authority, the Garden City Terminal handles 88% of all cargo that is shipped through the Port of Savannah. The team assumed the 88% cargo-handled figure attributed to the Garden City Terminal was identical to the percent of output and GDP attributable to the Garden City Terminal at the Port of Savannah. Since no additional information on the monetary value of each of the containers that came through the Port of Savannah (i.e. the average value of each piece of cargo handled) was available, the team could not definitively determine whether the 88% figure was also reflective of the total economic activity attributable to the Garden City Terminal.

#### **Average Working Weeks and Working Days per Year**

The study team assumed the average number of working weeks at the Garden City Terminal is 52 weeks, and the average number of working days per year is 365 days. This comports with convention and with the UGA study where we attained much of our economic input data. Though the team used 52 weeks, the Garden City Terminal is only “open” to ships Monday through Friday, with some limited hours on Saturday (GPA 2013). Thus, the actual number of “working days” may be less than 365 and the actual number of “working weeks” less than 52 weeks. However, for the sake of convention and consistency with the UGA Study, the team used 52 weeks and 365 days as our annual “working days” count.

### Diminished Port Capacity after a Hurricane

The final assumption the study team had to make in the economic impact analysis involved the extent to which the port would be operating due to a hurricane based on the length of time the port remained in an impaired condition. The study team defined informed assumptions about how the extent of inundation and damage will limit the terminal's handling capacity and the length of time this limited terminal capacity will persist. The extent of diminished operational capacity is expressed as a percentage of total operational capacity and was estimated based on recovery experiences at other ports after hurricanes. The time period for port shutdown is likewise estimated based on experiences at other ports in the United States and Caribbean. The team summarized the available data and was able to create an average hurricane recovery period, in terms of reduced capacity and recovery time for ports after category 1, 3, and 5 hurricanes. The study team was able to estimate the associated economic impact of each hurricane scenario using this recovery information and the economic input data provided in the UGA Study.

The study team's three post-hurricane recovery time lines are based on recovery time lines at different ports after particular hurricane events, though even ports affected by the same hurricane varied widely in their recovery time lines based on a variety of factors: (1) availability and extent of disaster relief assistance and resources; (2) damage to transportation networks, including road, rail and inland waterway networks; (3) effectiveness of the port's hurricane preparedness and recovery plan, and the extent to which the plans were followed; (4) level of storm surge; and (5) damage to critical infrastructure within the port, such as container cranes, warehouses and navigational tools.

First, the authors looked at the Port of New York-New Jersey and the impact Superstorm Sandy had on the container terminal within the Port. The New York-New Jersey container terminal is the busiest container terminal on the East Coast and the third busiest container terminal in the United States. The authors chose to look at the impact of Sandy on the Port of New York-New Jersey because it includes a container terminal similar to the Garden City Terminal and because sufficient information was available on the Port's recovery after Sandy to construct a reasonable recovery time line. Next, the team looked at Hurricane Rita's impact at the Port of Port Arthur in Port Arthur, Texas and the impact of Hurricane Ivan on the Port of St. George's in Grenada. The impacts of Hurricane Rita are somewhat conflated with the impacts Hurricane Katrina imposed on the port. However, because Hurricane Katrina had less of an impact on Port Arthur than it did on ports in Louisiana and Mississippi, the authors believe the impacts of Hurricane Rita can be reasonably estimated. The Port of St. George's is a smaller port that is vital to Grenada's economy. In September of 2004, category 3 Hurricane Ivan struck the Port of St. George's and caused substantial disruption to the Port's operations. However, due to generous outpourings of support from the international community and relief organizations, the Port returned to pre-hurricane levels fairly quickly. Finally, the team looked at Hurricane Katrina's impact on both the Port of New Orleans (including its large container terminal) in Louisiana and the Port of Gulfport in Mississippi. Hurricane Katrina was a category 5 hurricane, but quickly

dissipated to a category 3 storm upon landfall. Though the storm weakened upon landfall, its disastrous impact on Gulf Coast ports makes it an appropriate proxy for a category 5 hurricane for the purposes of this study.

#### Port Recovery Period: Category 1 Hurricane

Superstorm Sandy struck New Jersey and New York on October 29, 2012. Sandy hit land with sustained winds of 70 mph and was considered a post-tropical cyclone (approximately a category 1 Hurricane) (Smythe 2013). Sandy disrupted operations at the Port of New-York and New Jersey, and specifically disrupted operations at the Port's container facility for an extended period of time due to power outages and substantial flooding. The Port of New York-New Jersey includes the third busiest container terminal by number of TEUs handled in the United States. The container terminal was shut down for approximately a week, and regained full operations after four weeks. A more detailed description of the storm and its impacts on the container terminal are included in Appendix 4. Table 13 summarizes the average port recovery time for a category 1 hurricane.

**Table 13: Estimated Disruption at the Garden City Terminal due to a Category 1 Hurricane**

Disruption Characteristics	End of Week 1	End of Week 2	End of Week 3	End of Week 4
Extent of Capacity Reduced	90%	25%	10%	0%

#### Port Recovery Period: Category 3 Hurricane

To estimate damage from a category 3 Hurricane, the study team looked at the impact of Hurricane Ivan on the Port of St. George's in St. George's, Grenada and the impact of Hurricane Rita on Port Arthur in Port Arthur, Texas. Hurricane Ivan struck Grenada on September 7, 2004 as a category 3 Hurricane (World Bank 2005). The Port of St. George's in Grenada was initially overwhelmed by Ivan and remained closed for three days following the storm (World Bank 2005). The international community responded with overwhelming support to this disaster and sent much needed aid and supplies, which allowed the Port of St. George's to reach pre-hurricane operations after four weeks. Hurricane Rita hit made landfall as a category 3 hurricane on the Louisiana and Texas border on September 24, 2005. The port's emergency management team was permitted to enter the city on September 28 to start cleaning up the Port. In August of 2006, the Port of Port Arthur reported it was operating at pre-Hurricane Rita levels. Hurricane Rita's total economic damage was estimated at approximately \$10 billion at the Port itself (Pan 2011). A more detailed description of the storms and their impacts on the Port of St. George's and Port of Port Arthur are included in Appendix 4.



Table 14 summarizes the average port recovery time for a category 3 hurricane.

**Table 14: Estimated Disruption at the Garden City Terminal Due to a Category 3 Hurricane**

Disruption Characteristics	End of Week 1	End of Week 2	End of Week 3	End of Week 4	End of Week 5
Extent of Capacity Reduced	90%	50%	25%	10%	0%

### Recovery Period: Category 5 Hurricane

Finally, the study team estimated a port recovery period for a category 5 hurricane using Hurricane Katrina's impact on the Port of Gulfport in Gulfport, Mississippi and the Port of New Orleans in New Orleans, Louisiana. Hurricane Katrina was the most devastating hurricane to have ever hit the United States in recordable history, both in terms of human lives lost and economic impacts. The total number of fatalities directly and indirectly attributable to Hurricane Katrina was 1,833 deaths, and estimates of its total economic damage total approximately \$81.2 billion (Pan 2011). The team is aware that Hurricane Katrina was unique in the extent of its damage. Failures outside the Port of New Orleans and Port of Gulfport, such as levee failures and an anemic initial response by the government, made the economic impacts of Hurricane Katrina unique and more difficult to generally apply to other ports. However, the authors are confident that the port recovery periods after Hurricane Katrina can still be used to estimate potential economic impacts at the Garden City Terminal. Though Hurricane Katrina destroyed one-third of the Port of New Orleans (Grenzbeck & Lukmann 2008), the Port recovered to pre-hurricane capacity in just six months (U.S. Department of Commerce 2006). When Hurricane Katrina hit the Gulfport Port in Mississippi in 2005, its record-setting 25-foot storm surge knocked down container cranes, blew apart storage sheds, destroyed navigational aids and pushed barges hundreds of feet inland (Wright 2013). Reports indicate that even after five years and over \$250 million in new investments, the Port of Gulfport was still only operating at 80% of its pre-Katrina capacity (Wright 2013). A more detailed description of Hurricane Katrina and its impact on the Port of New Orleans and Port of Gulfport is included in Appendix 4. Table 15 summarizes the average port recovery time for a category 5 hurricane.

**Table 15: Estimated Disruption at the Garden City Terminal due to a Category 5 Hurricane**

Disruption Duration (in weeks)	1	2	3	4	8	12	16	20	24	28	32
Extent of Capacity Reduced	100%	90%	85%	80%	65%	55%	45%	35%	25%	10%	0%

## Economic Analysis Calculations at the Garden City Terminal

The following sections analyze the economic impact of category 1, 3, and 5 storms at the Garden City Terminal on Georgia's economy. The economic impact is measured in terms of reduced output and State GDP. A qualitative discussion regarding a hurricane's impact on employment and income and taxes was discussed above. This report used economic inputs provided by the University of Georgia's Selig Center for Economic Growth in its 2012 Report, "Economic Impact of Georgia's Deepwater Ports, FY 2011." The economic input data and methodology employed by the University of Georgia is found in Appendix 3 of this report.

## Economic Impact of a Category 1 Hurricane at the Garden City Terminal

This section examines the economic impact of a category 1 hurricane at the Garden City Terminal. As noted above, the economic impact is measured in terms of reduced output and State GDP. Table 16 below shows the economic outputs attributable to the Garden City Terminal and the Economic Impact of the Reduced Capacity based on the port recovery the team created for a category 1 hurricane.

**Table 16: Garden City Economic Outputs, Category 1 Hurricane**

Garden City Terminal Annual Economic Impact (\$ Million)	Output			State GDP		
	Direct	Indirect/ Induced	Total	Direct	Indirect/ Induced	Total
Port Industry	\$ 1,745	\$ 933	\$ 2,678	\$ 858	\$ 456	\$ 1,314
Port Users	\$ 25,097	\$ 17,983	\$ 43,056	\$ 10,379	\$ 10,605	\$ 21,026
Total Impact	\$ 26,841	\$ 18,916	\$ 45,734	\$ 11,237	\$ 11,061	\$ 22,340
Economic Impact of Reduced Capacity (\$ Million)						
Port Industry	\$42	\$22	\$64	\$21	\$11	\$32
Port Users	\$603	\$432	\$1,035	\$249	\$255	\$505
Total Impact	\$645	\$455	\$1,099	\$270	\$266	\$537

Looking at Table 16, the economic impact of reduced capacity was calculated by multiplying the economic output at the Garden City Terminal for each category by the reduced capacity of the Terminal. The reduced capacity of the Terminal encompasses both the extent of reduction in operational capacity (percentage figure) and the length of time that the port is operating at such reduced capacity. Table 17 summarizes the total economic impact of reduced capacity after a category 1 hurricane. It should be noted that this economic impact analysis only calculates the economic impact of operational delays at the Garden City Terminal.

Looking at Table 17, the total direct economic impact of a category 1 hurricane on Georgia's economy in terms of output is \$645,231,117. The total indirect and induced economic impact on Georgia's economy in terms of output is \$ 454,713,020. Adding the direct and indirect/induced output totals together produces a total economic impact of \$1,099,371,223 on Georgia's economy in terms of output in the event of a category 1 hurricane. The total direct economic impact of a category 1 hurricane on Georgia's economy in terms of State GDP is \$270,117,754. The total indirect and induced economic impact on Georgia's economy in terms of State GDP is \$265,896,795. Adding the direct and indirect/induced State GDP total together produces a total economic impact of \$537,021,699 on Georgia's economy in terms of State GDP in the event of a category 1 hurricane.

**Table 17: Economic Impact of a Category 1 Hurricane on the Garden City Terminal, Summary**

	<b>Direct</b>	<b>Indirect/induced</b>	<b>Total</b>
<b>Output</b>	\$645,231,117	\$ 454,713,020	\$ 1,099,371,223
<b>State GDP</b>	\$270,117,754	\$ 265,896,795	\$ 537,021,699

### **Economic Impact of a Category 3 Hurricane**

This section examines the economic impact of a category 3 hurricane at the Garden City Terminal. As noted above, the economic impact is measured in terms of reduced output and State GDP. The economic impact was found using the same methodology employed in calculating the impact of a category 1 hurricane, but included a longer recovery period. Table 18 below shows the economic outputs attributable to the Garden City Terminal and the Economic Impact of the Reduced Capacity based on the port recovery the team created for a category 3 hurricane.

**Table 18: Economic Output at Garden City Terminal, Category 3 Hurricane**

<b>Garden City Terminal Annual Economic Impact (\$ Million)</b>	<b>Output</b>			<b>State GDP</b>		
	<b>Direct</b>	<b>Indirect/Induced</b>	<b>Total</b>	<b>Direct</b>	<b>Indirect/Induced</b>	<b>Total</b>
Port Industry	\$ 1,745	\$ 933	\$ 2,678	\$ 858	\$ 456	\$ 1,314
Port Users	\$ 25,097	\$ 17,983	\$ 43,056	\$ 10,379	\$ 10,605	\$ 21,026
Total Impact	\$ 26,841	\$ 18,916	\$ 45,734	\$ 11,237	\$ 11,061	\$ 22,340
Economic Impact of Reduced Capacity (\$ Million)						
Port Industry	\$59	\$31	\$90	\$29	\$15	\$44
Port Users	\$845	\$605	\$1,449	\$349	\$357	\$708
Total Impact	\$903	\$637	\$1,539	\$378	\$372	\$752

Table 19 summarizes the total economic impact of reduced capacity after a category 3 hurricane. Looking at Table 19, the total direct economic impact of a category 3 hurricane on Georgia's economy in terms of output is \$903,323,564. The total indirect and induced economic impact on Georgia's economy in terms of output is \$ 636,598,228. Adding the direct and indirect/induced output totals together produces a total economic impact of \$1,539,119,712 on Georgia's economy in terms of output in the event of a category 3 hurricane. The total direct economic impact of a Category 3 hurricane on Georgia's economy in terms of State GDP is \$378,164,855. The total indirect and induced economic impact on Georgia's economy in terms of State GDP is \$372,255,513. Adding the direct and indirect/induced State GDP total together produces a total economic impact of \$751,830,379 on Georgia's economy in terms of State GDP in the event of a category 3 hurricane.

**Table 19: Economic Impact of a Category 3 Hurricane on the Garden City Terminal, Summary**

	<b>Direct</b>	<b>Indirect/Induced</b>	<b>Total</b>
<b>Output</b>	\$ 903,323,564	\$ 636,598,228	\$ 1,539,119,712
<b>State GDP</b>	\$ 378,164,855	\$ 372,255,513	\$ 751,830,379

### **Economic Impact of a Category 5 Hurricane at the Garden City Terminal**

This section examines the economic impact of a category 5 hurricane at the Garden City Terminal. As noted above, the economic impact is measured in terms of reduced output and State GDP. Table 20 below shows the economic outputs attributable to the Garden City Terminal and the Economic Impact of the Reduced Capacity based on the port recovery the team created for a category 5 Hurricane. The economic impact was found using the same methodology employed in calculating the impact of a category 1 and 3 hurricane, but included a longer recovery period.

The recovery period for a category 5 hurricane is substantially longer than for a category 1 or 3 Hurricane. Because category 5 hurricanes have only made landfall on a few occasions in recent history, data and information on the devastating impact of these storms was limited. This report used information from Hurricane Katrina's impact on the Port of New Orleans and the Port of Gulfport. The extended delays in reopening the ports to full capacity were confounded by breached levees, and thus massive flooding, poor planning, massive destruction to infrastructure outside the port, and a mass outflux of available labor. The team is aware that these additional storm-related occurrences may have exacerbated the port's recovery period. However, a category 5 storm would cause incredible destruction at the Garden City Terminal and communities surrounding the Terminal and may create the same kind of flooding, infrastructure damage and outflux of labor that Hurricane Katrina caused in New Orleans, Louisiana and Gulfport, Mississippi. Moreover, it is unclear whether the Terminal has an updated an effective hurricane plan in effect in the event of a massive hurricane. If the Terminal does not have a hurricane recovery plan in place, the recovery period could extend beyond eight months.

Table 20 summarizes the total economic impact of reduced capacity after a category 5 hurricane.

**Table 20: Economic Output at Garden City Terminal, Category 5 Hurricane**

Garden City Terminal Annual Economic Impact (\$ Million)	Output			State GDP		
	Direct	Indirect/ Induced	Total	Direct	Indirect/ Induced	Total
Port Industry	\$ 1,745	\$ 933	\$ 2,678	\$ 858	\$ 456	\$ 1,314
Port Users	\$ 25,097	\$ 17,983	\$ 43,056	\$ 10,379	\$ 10,605	\$ 21,026
Total Impact	\$ 26,841	\$ 18,916	\$ 45,734	\$ 11,237	\$ 11,061	\$ 22,340
Economic Impact of Reduced Capacity (\$ Million)						
Port Industry	\$515	\$275	\$790	\$253	\$135	\$388
Port Users	\$7,408	\$5,309	\$12,710	\$3,064	\$3,131	\$6,207
Total Impact	\$7,923	\$5,584	\$13,500	\$3,317	\$3,265	\$6,595

Looking at Table 21, the total direct economic impact of a category 5 hurricane on Georgia's economy in terms of output is \$7,923,438,121. The total indirect and induced economic impact on Georgia's economy in terms of output is \$ 5,583,875,885. Adding the direct and indirect/induced output totals together produces a total economic impact of \$13,500,278,613 on Georgia's economy in terms of output in the event of a category 5 hurricane. The total direct economic impact of a category 5 hurricane on Georgia's economy in terms of State GDP is \$3,317,046,014. The total indirect and induced



economic impact on Georgia's economy in terms of State GDP is \$3,265,212,641. Adding the direct and indirect/induced State GDP total together produces a total economic impact of \$6,594,626,469 on Georgia's economy in terms of State GDP in the event of a category 5 hurricane.

**Table 21: Economic Impact of a Category 5 Hurricane on the Garden City Terminal, Summary**

	<b>Direct</b>	<b>Indirect/induced</b>	<b>Total</b>
<b>Output</b>	\$7,923,438,121	\$ 5,583,875,885	\$ 13,500,278,613
<b>State GDP</b>	\$ 3,317,046,014	\$ 3,265,212,641	\$ 6,594,626,469

### Physical Port Damage from Storm Surge

Storm-surge related damage to the Garden City Terminal depends on both the frequency of storm surges and the height of the surge. The National Oceanic and Atmospheric Administration (NOAA) maintains a software tool that predicts storm surge based on different hurricane scenarios, topography, and water basin characteristics. The model, called the Sea, Lake and Overland Surges from Hurricanes (SLOSH), produces storm surge inundation maps, which can then feed models predicting disruptions to economic activity or infrastructure damage (National Hurricane Center, 2013). A detailed description of SLOSH is included in Appendix 6. The Naval Research Laboratory, Marine Meteorology Division, used the SLOSH model to estimate water heights at the Garden City Terminal under hurricane categories one through five (Naval Research Laboratory 2008). The results of the SLOSH model predict a storm surge ranging from 13.6 feet to 28.1 feet above mean tide (

Table 22). The tidal range at the Garden City Terminal is 7.5 feet, meaning that resulting storm tide could be 3.75 feet higher or lower depending on the astronomical tide at the moment of hurricane impact. As previously stated, the piers at the Garden City Terminal are 7.5 feet above mean high tide, which equates to 11.25 feet above mean tide, indicating that even a category one storm would likely flood much of the terminal, even at current sea levels.

**Table 22: Storm surge predicted by the SLOSH model at the Garden City Terminal (given existing sea levels)**

<b>Hurricanes</b>	<b>Max Storm Surge above Mean Tide (ft.)</b>
<b>Category 1</b>	13.6
<b>Category 2</b>	17.2
<b>Category 3</b>	21.4
<b>Category 4</b>	24.9
<b>Category 5</b>	28.1

*Source: Naval Research Laboratory, n.d.*

Hurricanes have not struck Georgia directly in the past decades. The last hurricane to impact the Georgia coast directly was Hurricane David in 1979 (category 2). However, storms have occurred more frequently over Georgia's history. Since 1800, 31 storms have impacted Georgia, 23 of which were after 1850. According to the Georgia Emergency Management Agency, category 1 storms account for the majority of hurricanes (2013). No category 5 storms have directly struck the Georgia coast since 1851. Table 23 below shows the number of storm occurrences since 1850 and the derived probability per year based on the 163 years of observation.

**Table 23: Hurricane occurrences affecting Georgia since 1850 by category of storm**

<b>Category of Hurricane</b>	<b>Occurrences since 1850*</b>
<b>Category 1</b>	15
<b>Category 2</b>	5
<b>Category 3</b>	2
<b>Category 4</b>	1
<b>Category 5</b>	0

*Source: Georgia Emergency Management Agency 2013*

\*A majority of the 23 hurricanes occurred before 1900

The Port of Savannah could minimize damage by preparing for hurricanes. The U.S. Navy does not consider docks at the Garden City Terminal to be safe for ships during a hurricane, and the Coast Guard inspects port preparation with facility operators 48 hours before the expected arrival of gale force winds and closes the harbor no later than 12 hours in advance (Naval Research Laboratory 2013). The Coast Guard also recommends that all seagoing vessels leave the port to avoid the storm (U.S. Coast Guard 2013). While the Georgia Ports Authority has a mobile command center that can direct port operations remotely in case of storm (Georgia Ports Authority 2013), the Coast Guard requires a suspension of port cargo operations during severe storms (U.S. Coast Guard 2013). A strong hurricane plan might further increase port preparedness.

### **SLOSH at the County-Level**

The study team produced results quantifying property exposure for each hurricane category with and without storm surge at the level of the county as a whole, with particular focus on the Garden City Terminal and Chatham County warehouses. The results include the following variables:

- Area (acres and percentage)
- Building value (value and percentage)
- Land value (value and percentage)
- Max flood height (feet)

- Mean flood height (feet)

### SLOSH Methodology

The study team estimated flooding using the SLOSH model in the Savannah basin by using built-in scenarios for hurricanes of category 1 through 5 that aggregate the maximum wave heights for a variety of different storm locations, speeds, and directions. The study team overlaid SLOSH flooding output with a parcel file provided by the Chatham County Board of Assessors in ArcGIS to determine the parcels that were fully or partially inundated by storm surge for different hurricane categories at current sea levels. The study team identified the flooded parcels for each scenario and built a table with acreages, building value, land value, and flood height for each. This initial analysis provided the aggregate characteristics for the parcels that were vulnerable to storm surge at current sea levels for five different hurricane categories. A more detailed SLOSH methodology is provided in Appendix 6.

### Chatham County

The study team first analyzed SLOSH output at the scale of Chatham County because Chatham County contains the Garden City Terminal, the majority of nearby warehouses, the largest number of port employees, and the closest vulnerable transportation links. The analysis revealed the coastal and riverside areas to already be very vulnerable to storm surge from lower category hurricanes, and all but the highest elevation areas vulnerable to storm surge from higher category hurricanes. Those high elevation areas include the bluff upon which the historic downtown is built and the high ground at the Savannah regional airport. However, many residential areas and transportation links are located in much lower elevation areas with increased storm surge risk.

The study team overlaid SLOSH flooding output with parcel data to display the areas most vulnerable to storm surge at current sea levels. Figure 20 shows that a category 1 storm would cause flooding along the coast and the counties' rivers. The Savannah River, along which the Garden City Terminal is built, would experience limited flooding. Figure 21 shows that flooding is much more widespread for a category 3 hurricane. Indeed, most of the county is flooded, and flooding is severe along the coast and the Savannah River. A category 5 storm in Figure 22 would flood nearly all of the county, with extremely severe flooding along the Savannah River, with water levels on the river as much as 34 feet above normal.

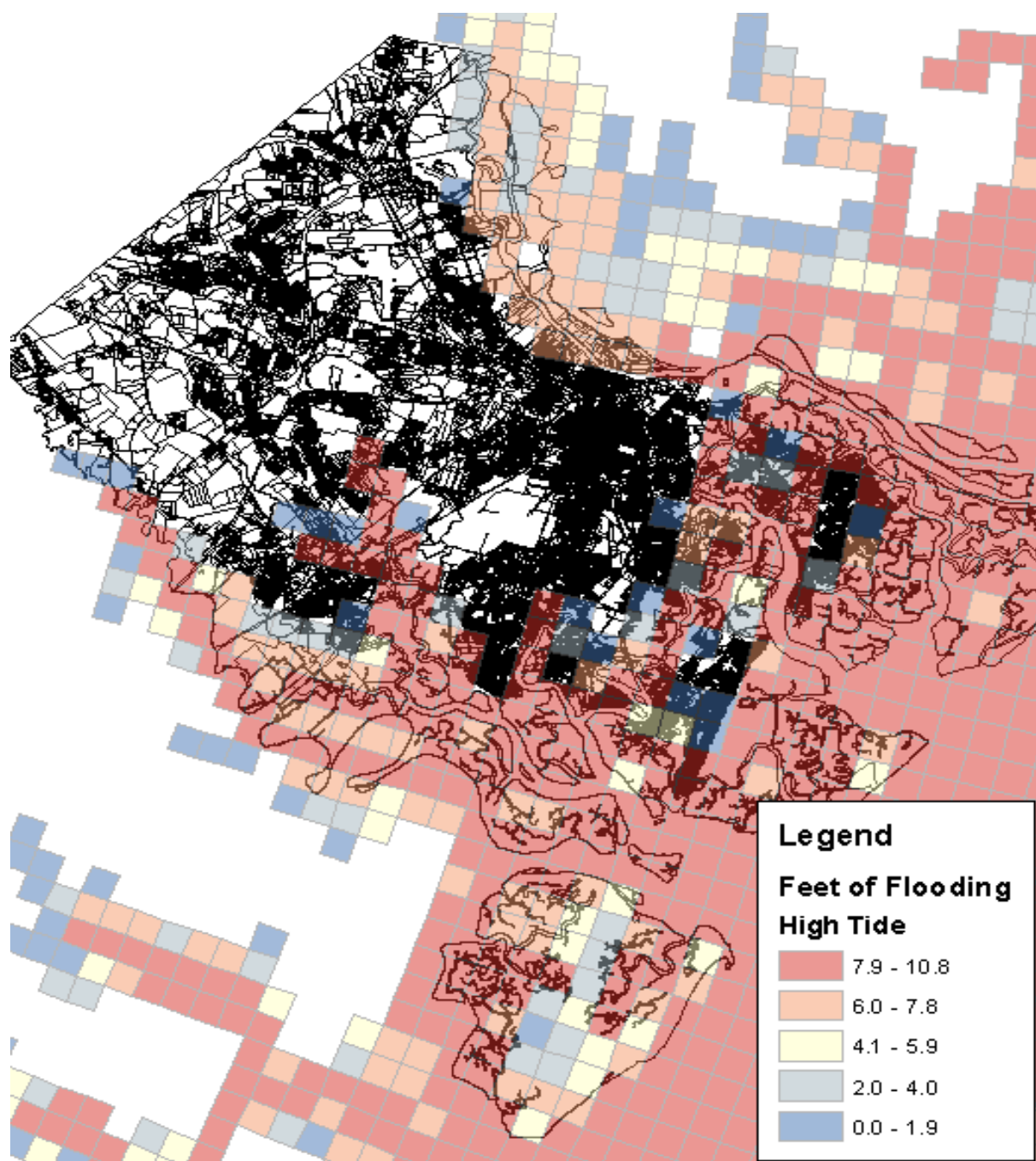


Figure 20: Storm Surge with Category 1 Hurricane in SLOSH, Chatham County

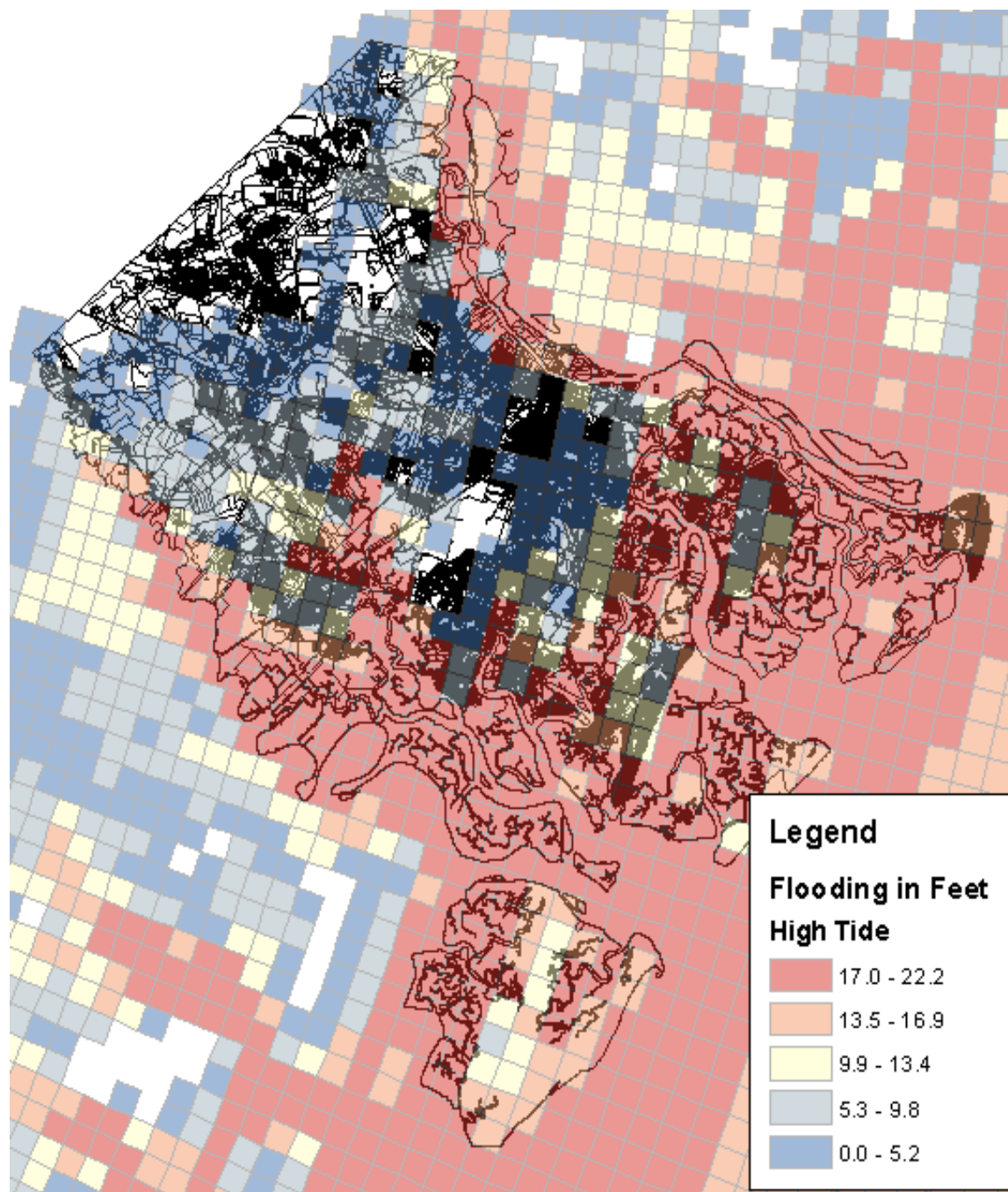


Figure 21: Storm Surge with Category 3 Hurricane in SLOSH, Chatham County



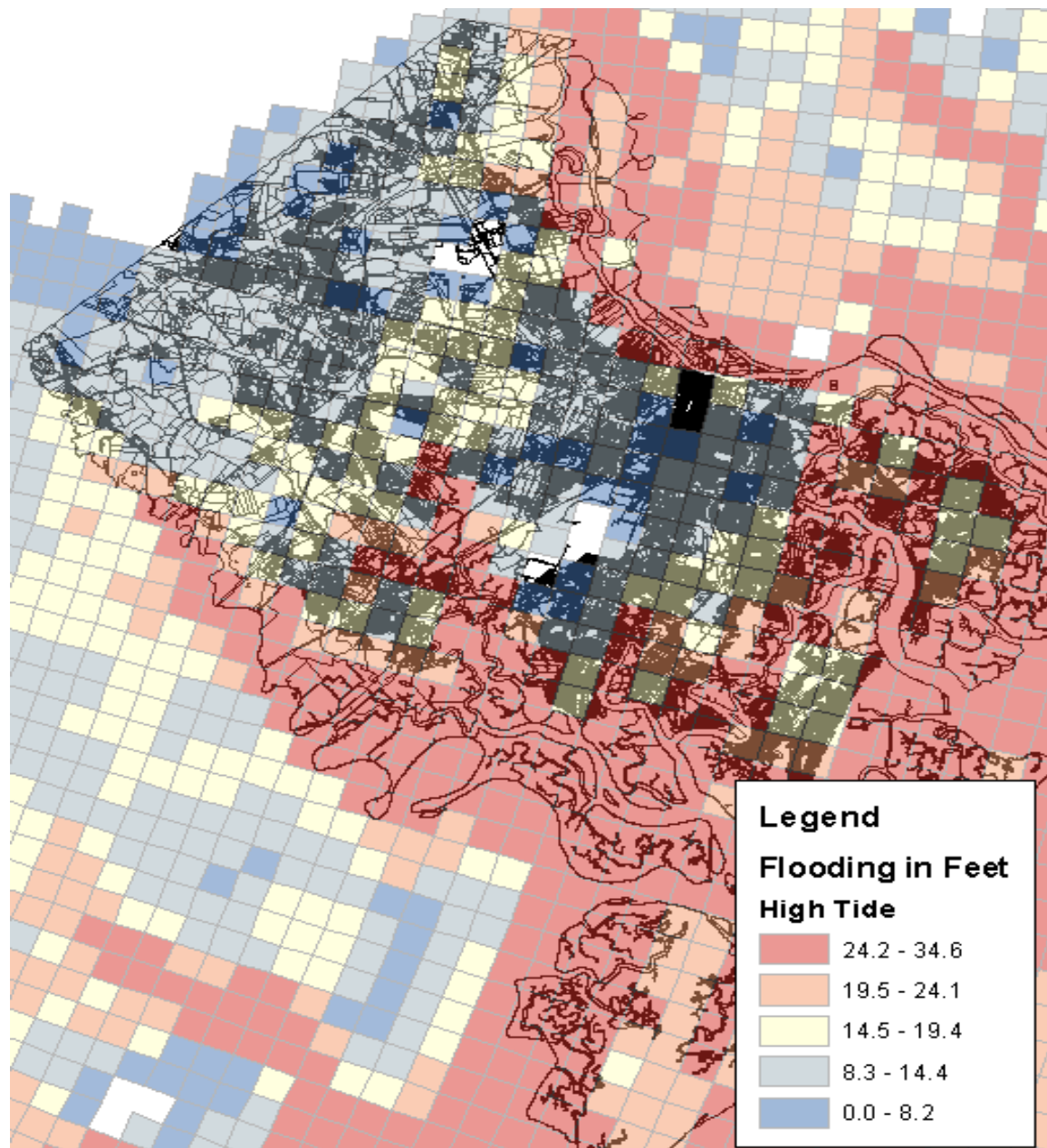
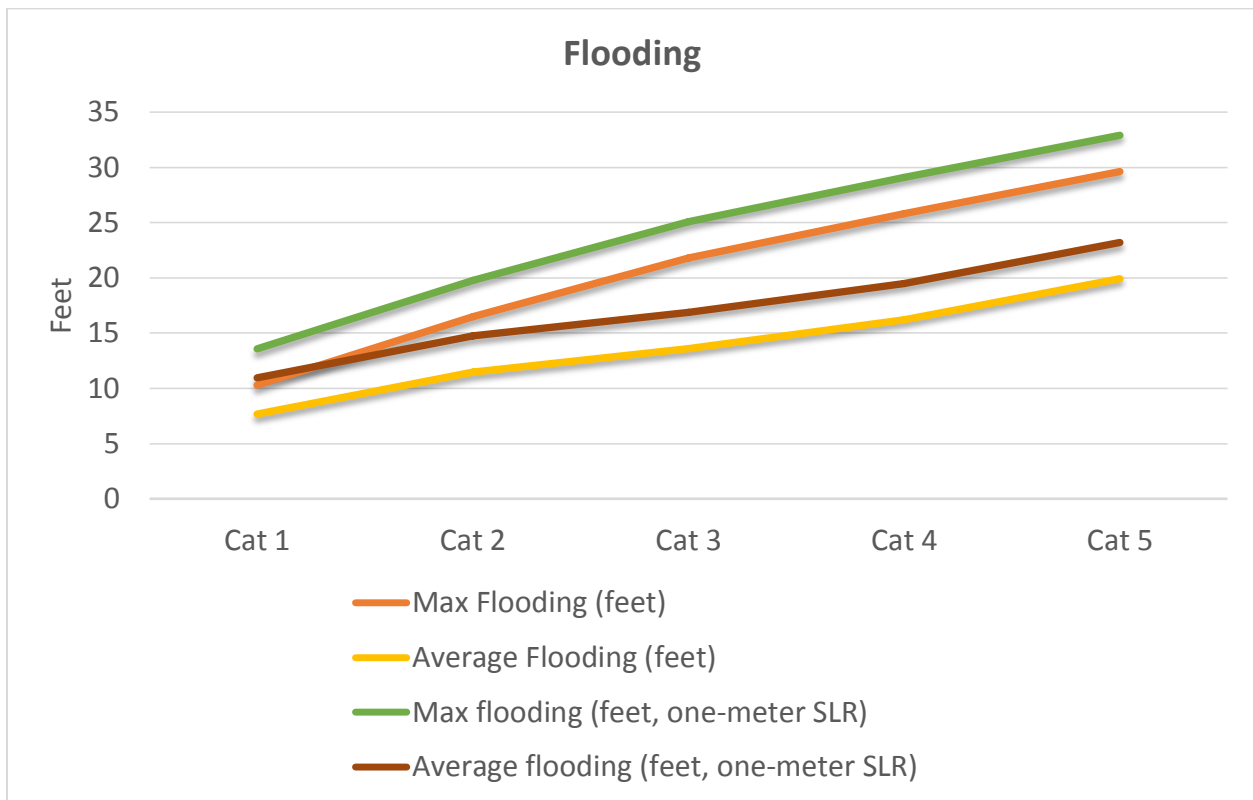


Figure 22: Storm Surge with Category 5 Hurricane in SLOSH, Chatham County

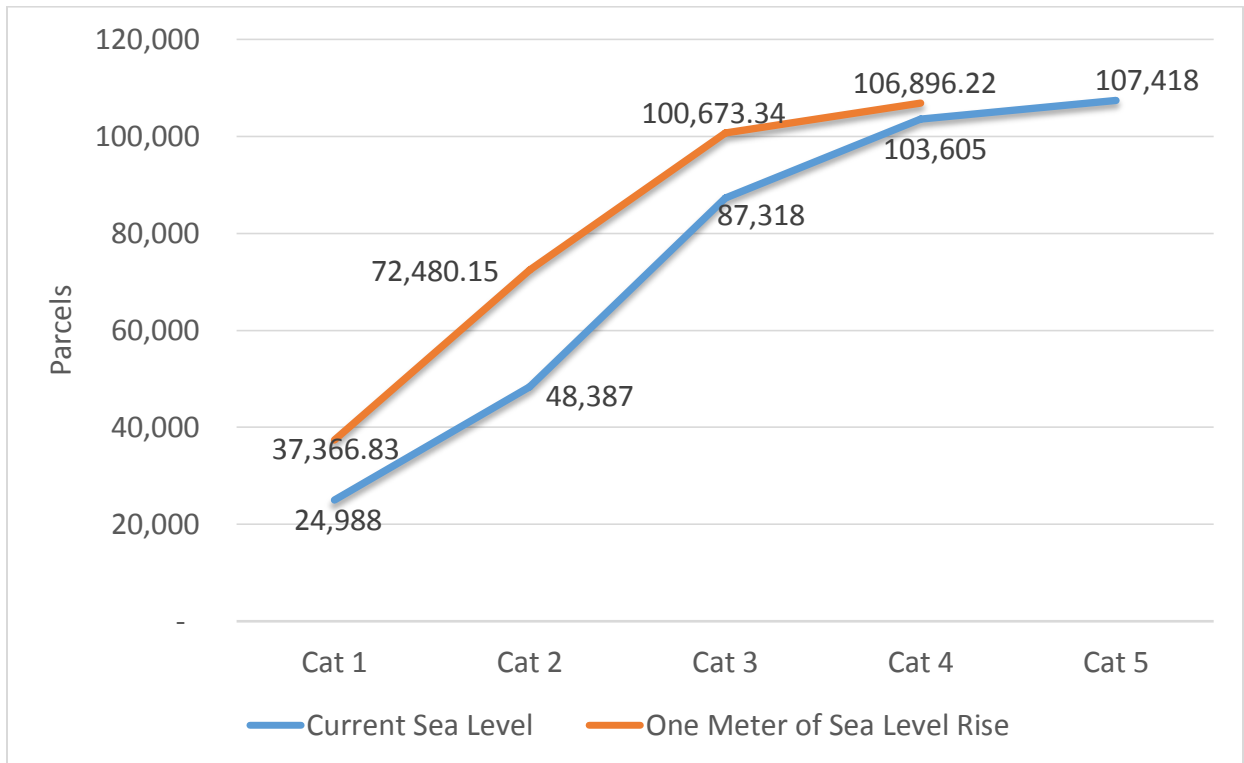


Sea level rise is expected to increase the entire county's vulnerability to storm surge by making all storm surges approximately one meter higher relative to land in 100 years. Sea level rise will increase flooding's reach in the county and make it more severe. Figure 23 shows the expected impact that sea level rise will have on average flooding and maximum flooding for different storm categories. For a category 5 storm, sea level rise will push maximum flooding over 30 feet above ground level and will produce average flooding over 20 feet above ground level in Chatham County.



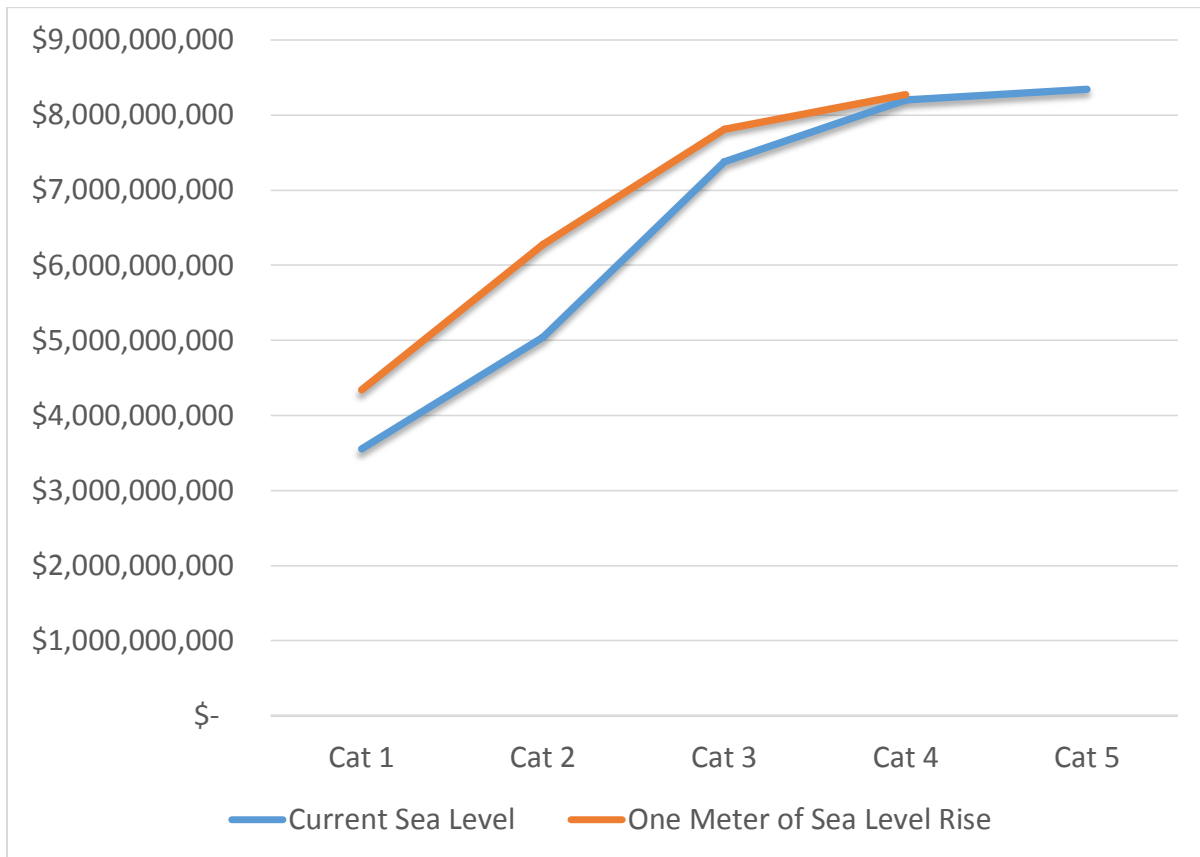
**Figure 23: Storm Surge Related Flooding in Chatham County**

Higher sea levels will increase the number of properties in Chatham County affected by storm surge, especially for categories 1, 2, and 3. Category 4 and 5 storms would flood most of the county even at sea levels, so sea level rise causes a more modest increase in the number of parcels flooded. Still, sea level rise would increase flooding severity by approximately one meter over all flooded parcels (Figure 24), increasing damage to buildings, infrastructure degradation, and threats to human life.



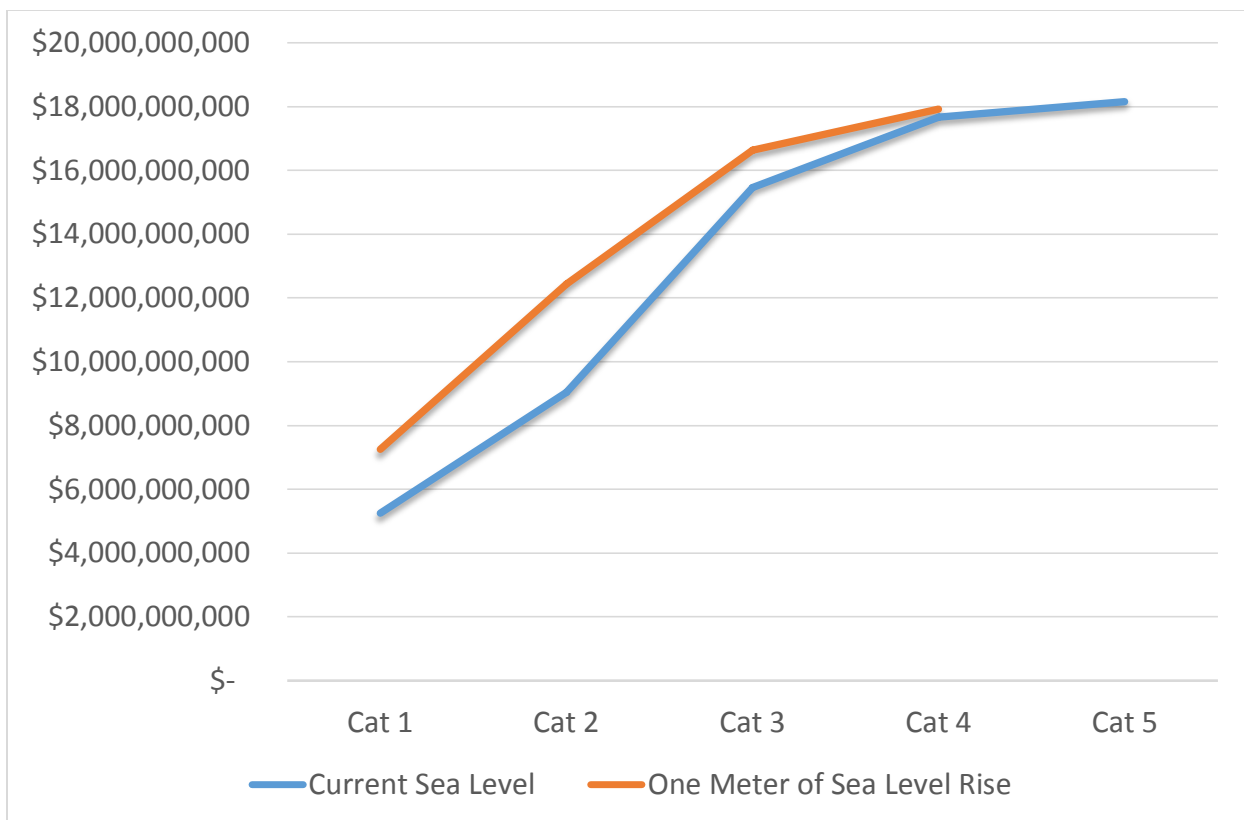
**Figure 24: Number of Parcels Affected by Storm Surge**

Today, a category 1 hurricane in the Savannah area would produce an average storm surge of approximately 7.7 feet and a maximum storm surge of 10.3 feet, which would rise to 13.3 feet with 3 feet of sea level rise. The sea level rise would increase the number of Chatham County parcels affected from 24,988 to approximately 43,509. These parcels' economic value can be summarized by the appraised value of the land that they occupy and the value of the buildings on them. The fully or partially flooded parcels' aggregate land value would increase from \$3.6 billion for a category 1 storm at current sea levels to \$4.7 billion with one meter of sea level rise (Figure 25).



**Figure 25: Land Value of Parcels Affected by Storm Surge, Chatham County**

Storm surge from a category 1 storm at current sea levels threatens to damage or destroy \$5.2 billion worth of buildings in Chatham County, which would increase to \$8.2 billion worth of buildings with one meter of sea level rise (Figure 26). The building value is particularly important because it is the property most easily damaged in a hurricane and because people who do not leave the county take shelter in buildings during hurricanes. Thus, sea level may significantly increase the building stock's susceptibility to flooding and hurricane damage even with low category hurricanes. The same increases hold true at higher storm categories too. Sea level rise may increase the affected parcels in a category 4 storm from 103,605 with a building value of \$17.7 billion to 106,623 parcels with a building value of \$18.1 billion dollars. By comparison, Chatham County's entire building stock is worth \$20.5 billion, meaning that a category 4 hurricane with sea level rise would threaten up to 88% of the county's building stock by value.



**Figure 26: Building Value of Parcels Affected by Storm Surge, Chatham County**

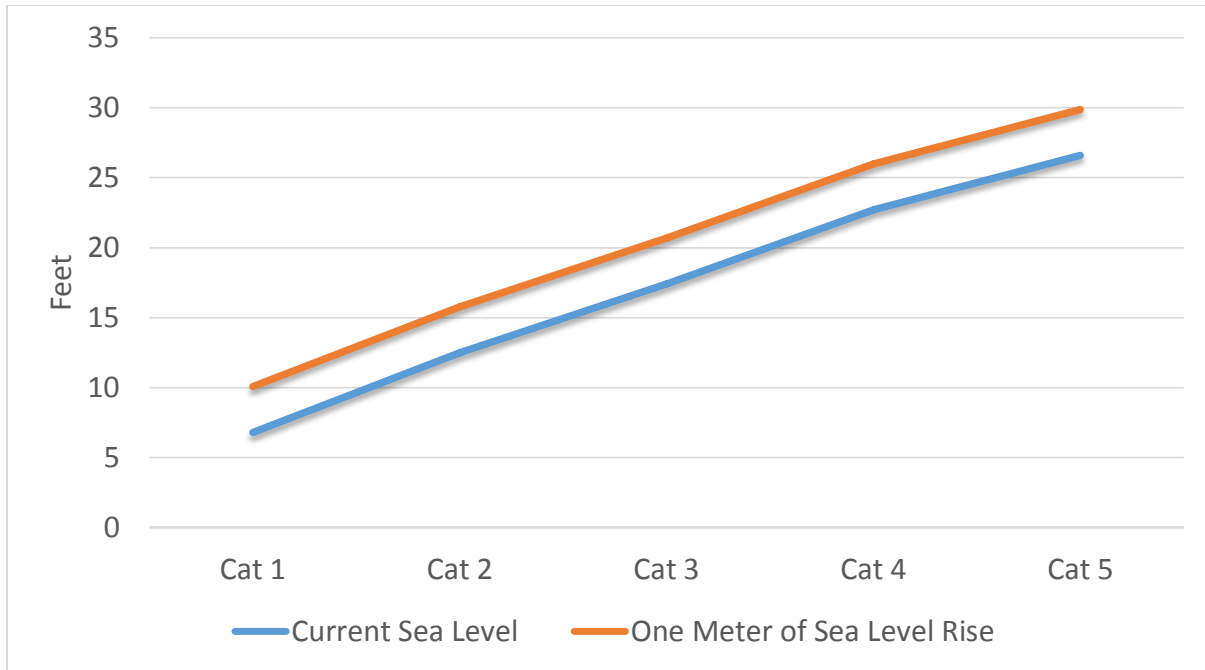
In Appendix 9 provide a table of Chatham County's direct economic vulnerabilities to hurricanes with and without sea level rise.

### **The Physical Impacts of Storm Surge at the Garden City Terminal**

The Garden City Terminal is directly adjacent to the Savannah River. While the location is necessary for operations, the river's adjacency makes the Terminal very vulnerable to storm surge. The Garden City Terminal's wharves are just 7.5 feet above high tide, or roughly 11.25 feet above mean tide. The Terminal is predominantly flat, offering little protection from waves. Moreover, the basin's shape allows waves to propagate up the river. The container crane, gantry cranes, electrical infrastructure, stored containers, jockey trucks, buildings, and other equipment are worth tens of millions of dollars and may not all be able to be moved or adequately protected from storms. In addition to the building and equipment value, damage to the port may temporarily require its closure, negatively affecting the employees and industries that work in and depend on the port in Chatham County and the must border region. Thus, increasing port flooding is a major economic threat.

A category 1 hurricane today at high tide would cause waves 13.6 feet above mean tide in the Savannah River adjacent to the Garden City Terminal (Naval Research Laboratory n.d.). These waves would likely overtop the wharf heights, which are 11.25 feet above mean tide. The SLOSH model output confirmed that a category one storm would likely flood portions of the Garden City Terminal even at current sea level. One meter of sea level rise would cause category one storm surge to rise to approximately 16.6 feet above mean tide. If port infrastructure is not prepared appropriately, the rise in wave height would worsen port inundation.

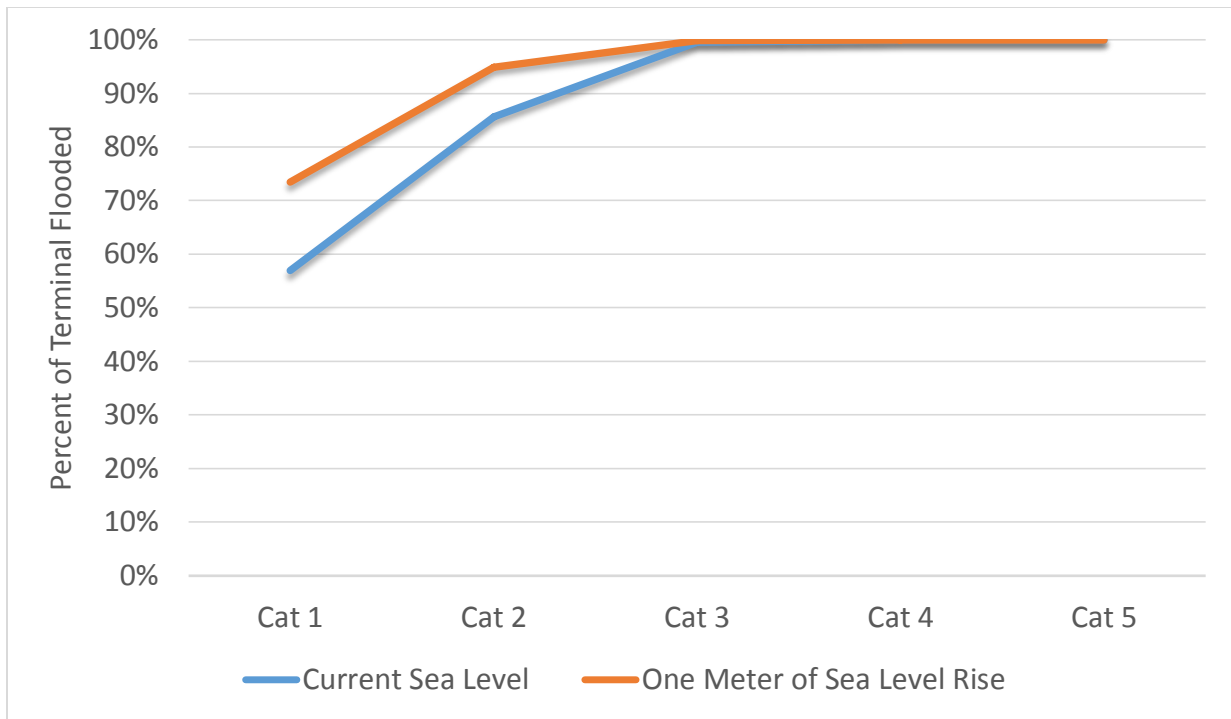
Figure 27 below shows maximum storm-induced flooding at a representative site in the Garden City Terminal for different hurricane categories with and without sea level rise. Sea level rise increases flood height by approximately 30% for category 1 storms. category 5 storms without sea level rise could see over 25 feet of flooding at current sea levels, which sea level rise may increase to nearly 30 feet. Such severe flooding would cause immense devastation at the terminal.



**Figure 27: Height of Storm Surge above Sample Ground Level at the Garden City Terminal**

The port areas most endangered by storm surge are directly adjacent to the river, where the large container cranes are located, and along the storm water drainage basin that bisects the port. One meter of sea level rise would raise the wave level from 6.8 feet to 10.08 feet, making widespread port flooding much more likely even with the lowest category storms. The effect is more pronounced for category 2 storms, which would increase port flooding from an average of 1.4 feet above ground to 4.68 feet above ground, flooding approximately 94% of the Terminal.

Figure 28 below shows how sea level rise may increase the percent of the port that is flooded. Storms above category 2 would flood the entire terminal, and sea level rise will increase the water level and result in more severe damage and longer port closures. To illustrate, a category 5 storm with sea level rise risks flooding the terminal with 19.2 feet of water, which would cause very significant damage to all infrastructure and equipment at the Garden City Terminal.



**Figure 28: Percentage of Garden City Terminal Flooded Due to Storm Surge**

The appendix includes detailed flood height and extent statistics derived from the SLOSH model.



### Warehouse Damage in Chatham County

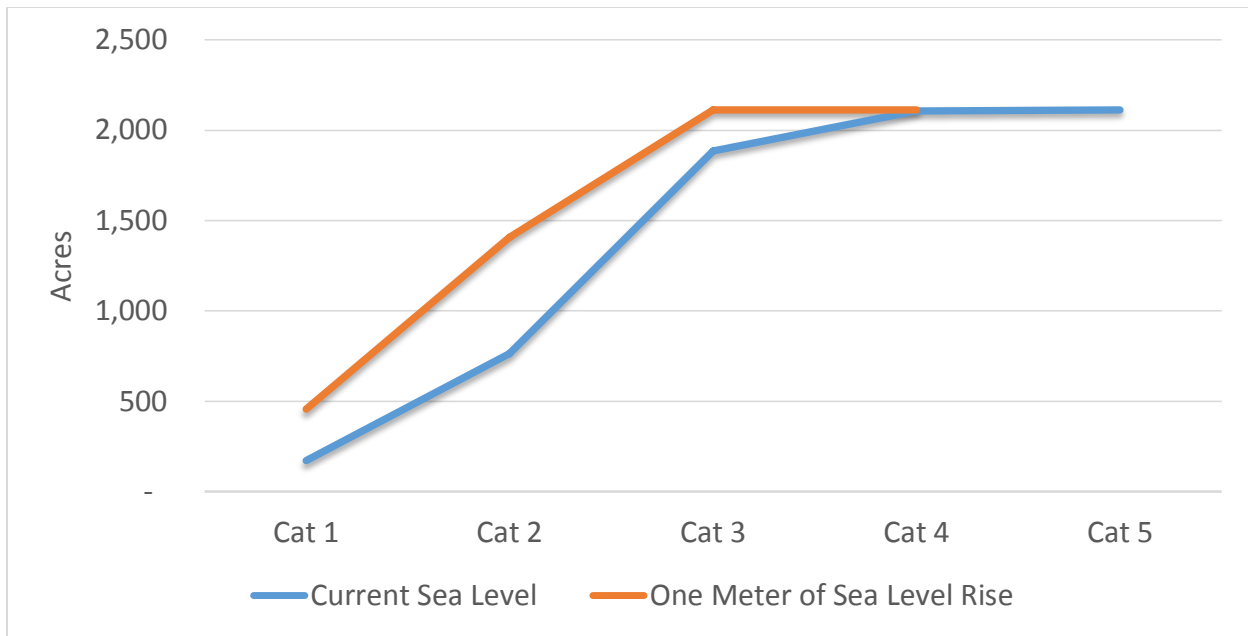
Chatham County contains 2,147 acres of warehouses owned by a large variety of company types, as shown in Table 24. These warehouses have buildings worth \$896 million and are built on land worth \$167 million. While not all warehouses have direct port-related activity, many—particularly in west Chatham County—receive deliveries from the port, process these deliveries, and ship the final product to customers in the rest of the Southeast. Port-related supply chains depend to a large degree on these warehouses functioning. Table 6 below provides warehouse value and coverage statistics derived from a database provided by the Chatham County Board of Assessors.

**Table 24: Warehouses in Chatham County**

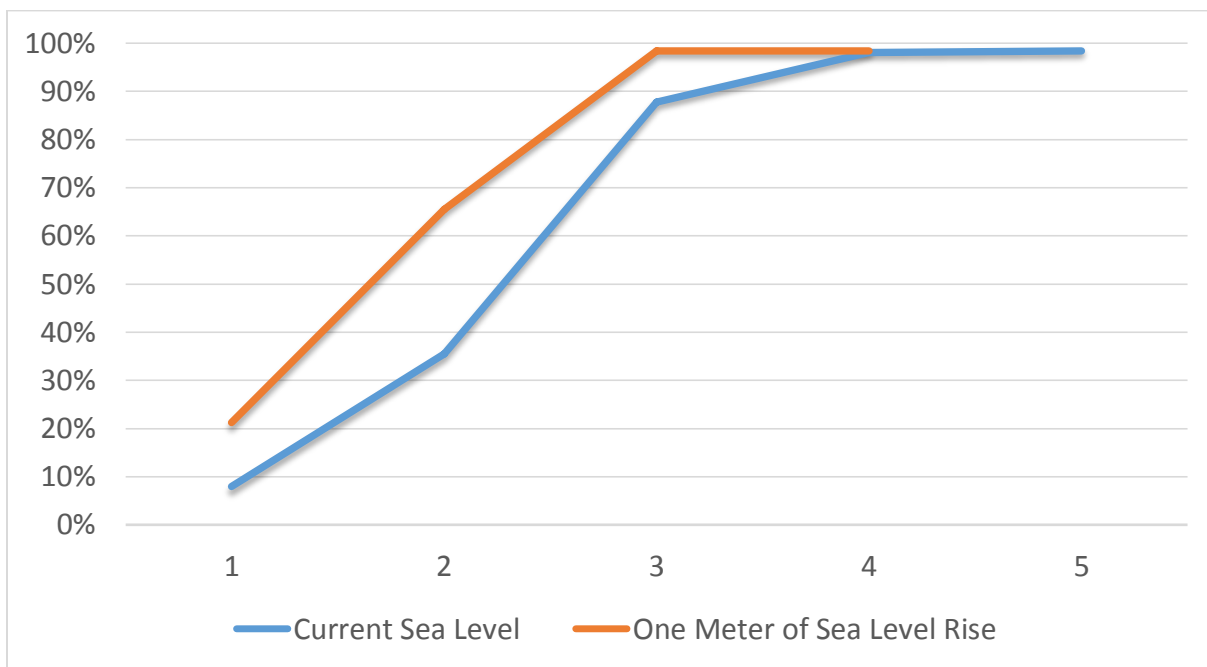
<b>Total Warehouse Area (acres)</b>	2,147
<b>Total Warehouse Building Value</b>	\$896,204,735
<b>Total Land Value</b>	\$167,121,902

Today's category 1 storms are likely to cause storm surge flooding of part of 8% of the county's warehouse acres, mostly located near the coast and the Savannah River. It is important to note that some of the largest warehouses are located in low lands in northern Chatham County within approximately half a mile of the Savannah River with few natural barriers. This includes large warehouses operated by IKEA and Target. Sea level rise is likely to increase the percentage of acreage flooded in a category 1 storm from 72 acres to 432 acres, or from 8% to 20% of total warehouse acres in Chatham County.

Figure 29 and Figure 30 below show how sea level rise will increase the warehouse parcels affected by inundation by acres. Sea level rise has the biggest impact for category 1, 2, and 3 storms. By categories 4 and 5, nearly 100% of the county's warehouses would be fully or partially inundated by storm surge at current sea levels. Sea level rise will increase storm surge's damage severity for higher category storms even if it does not increase the number of warehouses affected.



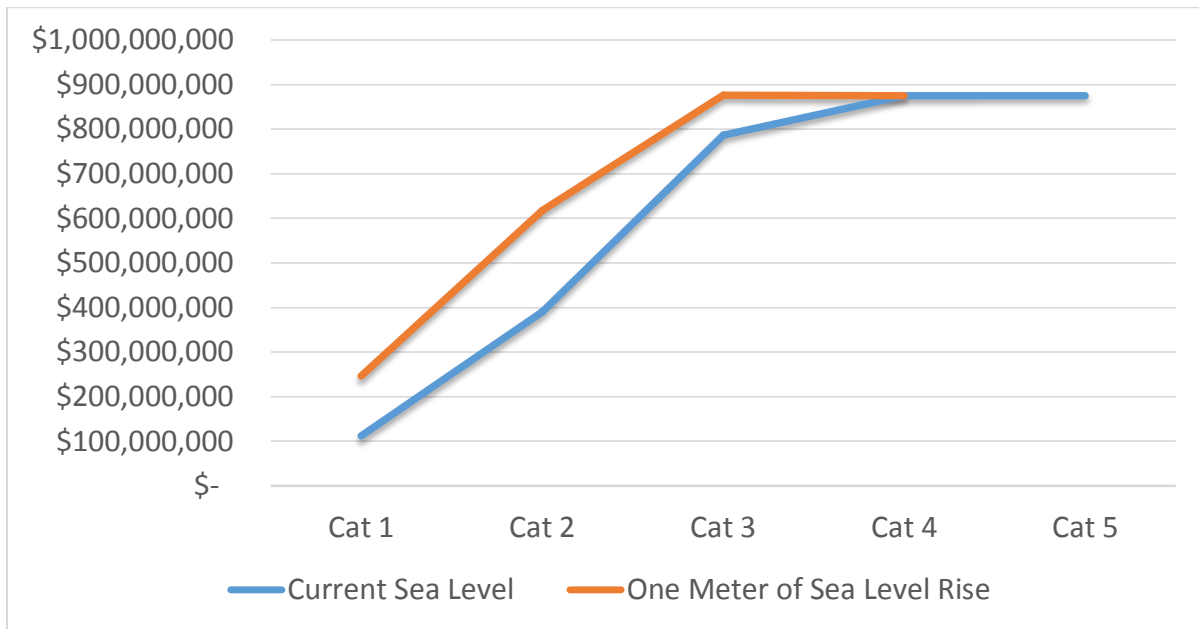
**Figure 29: Acreage of Warehouses Affected by Storm Surge**



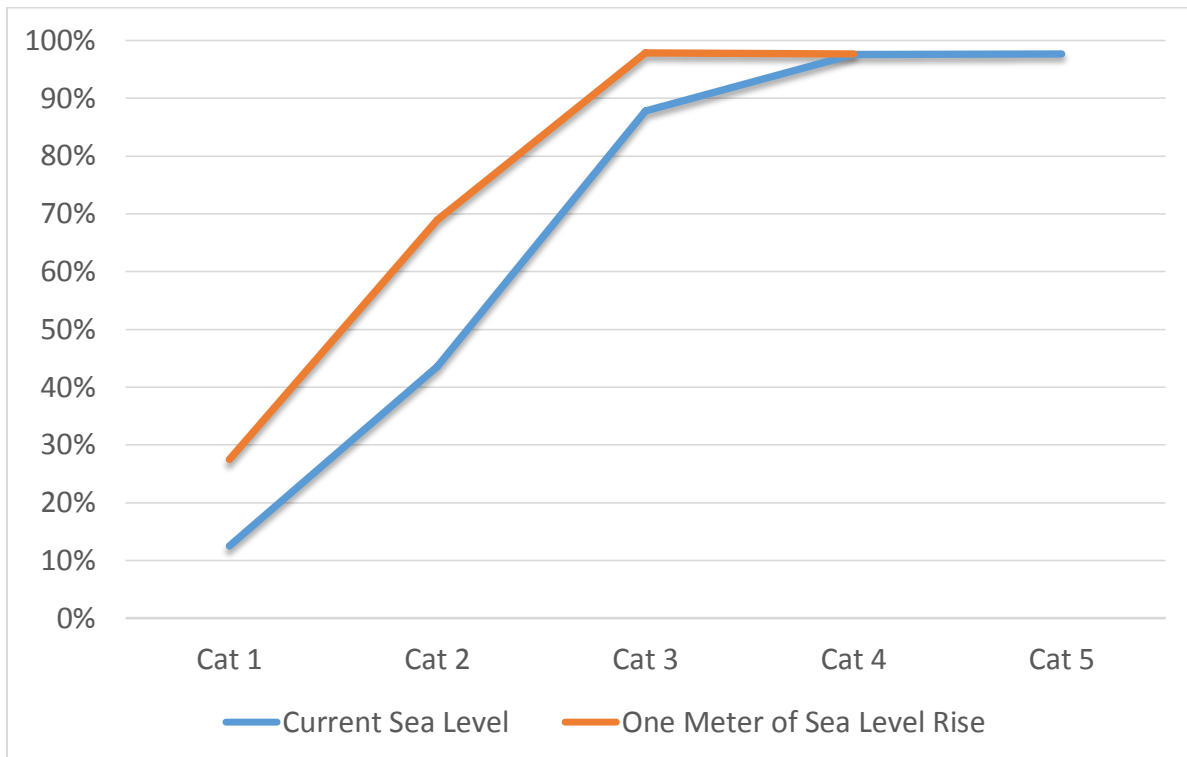
**Figure 30: Percentage of Warehouse Acres Affected by Storm Surge**

Sea level rise is also likely to increase a category 1 storm surge's effect from affecting buildings worth \$112 million to buildings worth \$235 million. Figure 31 and Figure 32 below illustrate the warehouse building value that may be exposed to storm surge at current sea levels and with one meter of sea level rise. The increase is similar to the warehouse acreage exposure. Sea level rise has the biggest effect for increasing the number of buildings exposed to storm surge for categories 1, 2, and 3. Category 4 and

5 hurricanes are likely to flood most warehouses in the county with or without sea level rise, though sea level rise will aggravate the damage. The building stock vulnerable is worth nearly \$900 million.

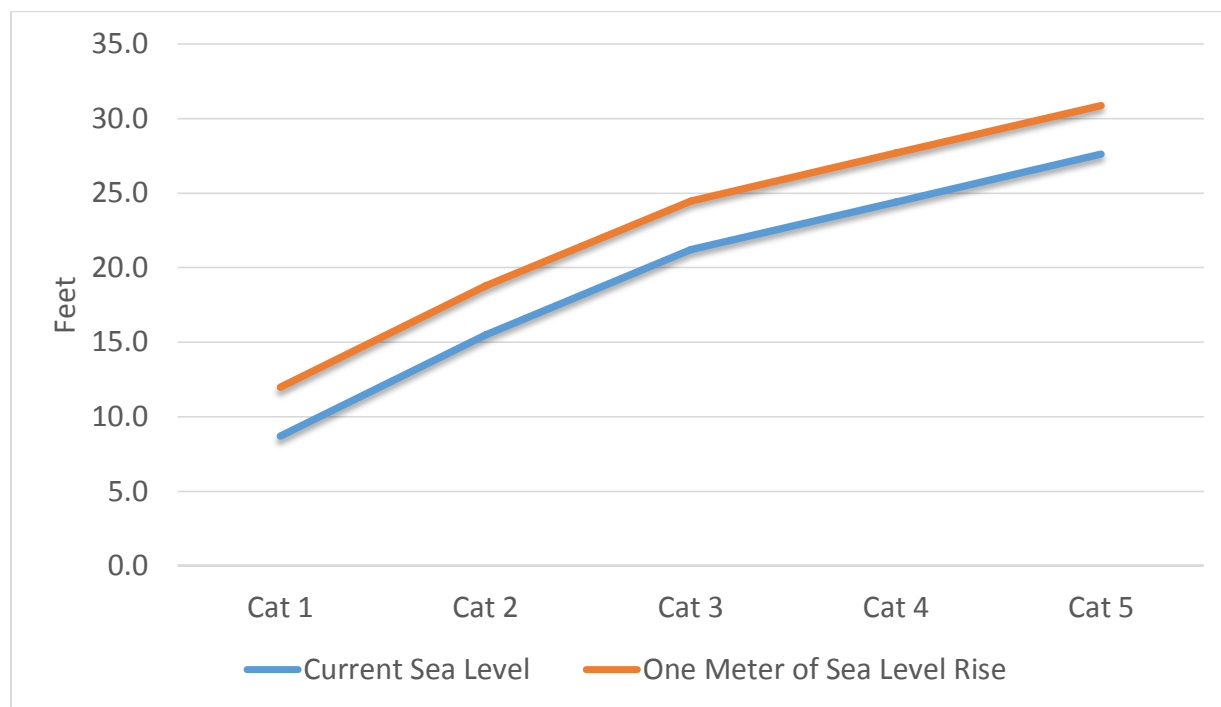


**Figure 31: Building Value of Warehouses Affected by Storm Surge**



**Figure 32: Percentage of Building Value of Warehouses Affected by Storm Surge**

Figure 33 below illustrates the maximum storm surge flooding seen at warehouses and the increase caused by one meter of sea level rise. Maximum flooding at warehouses for category 5 storms with sea level rise may exceed 30 feet above ground



**Figure 33: Maximum Storm Surge Flooding in Chatham County**

The appendix includes detailed tables with warehouse vulnerability by value and acreage.

## Conclusions

Increased vulnerability to storm surge is one of the greatest threats to port-related economic activity posed by sea level rise. It threatens the economy in two regards. First, storm surge will damage the very expensive capital investments made in Chatham County, necessitating re-investment in rebuilding the physical capital stock instead of other productive investments. Chatham County parcels have buildings assessed at a value of nearly \$21 billion, which are potentially vulnerable to storm surge damage. The Garden City Terminal's value is at least \$105 million according to the Chatham Board of Tax Assessors. This figure does not even include the 27 container cranes and the 8 new cranes valued at approximately \$12 million each. Warehouses in Chatham County have buildings worth \$896 million, most of which higher category hurricanes with sea level rise will threaten.

Second, storm surge may close the port, dislocate workers, damage highways and railroad tracks, damage port equipment, or flood warehouses, all of which may hinder the Terminal's ability to function at full capacity. A partial port closure, which is common with hurricane strikes, will result in lost productivity and disrupted freight flows with a very real economic cost throughout the coastal region and State of Georgia.

## CITY OF DARIEN INTRODUCTION

Located at the mouth of the Altamaha River, the City of Darien has a vibrant history. Now a small, quiet town of 1,975 people, Darien was once a major port along Georgia's coast. Founded in 1736 by General James Oglethorpe, it is Georgia's second oldest planned community.

According to the 2010 Census, there are a total of 798 households in Darien. Of these, 248, or 31%, have children under the age of 18 and 63.4% are owner occupied. Although small, the population has steadily grown in recent decades with a 13% increase from 2000-2010.

A number of the town's population characteristics present an economic development challenge. According to the 2011 ACS 5 Year Estimates, only 15% of the population over the age of 25 has earned a bachelor's degree or higher as opposed with 27.5% statewide. For the population aged 18-24, the numbers drop significantly and only 43.4% have graduated from high school. The Median Household Income in Darien is \$34,098, and the unemployment rate in McIntosh County in July 2013 was 10.4%. This was significantly higher than the national rate of 7.4% at the same point in time (Bureau of Labor Statistics).

As a small, rural community, Darien has a much less diverse economy than a large city like Savannah, which may lead to the impacts of SLR being felt more acutely within the city's key industries. This report analyzes three areas of the local economy that would most likely be affected by SLR: commercial fishing, tourism & small businesses, and residential real estate.

Given the differences between Darien's economy and the economic activity at the Port of Savannah, it was important to approach the economic impact analysis in a different way. For Darien, it was essential to gain a thorough understanding of how these smaller industries operated in order to draw a connection between the environmental impact of SLR and the daily life of the workers and residents of Darien. The team found that the most severe economic impacts would likely be felt by the fishing industry and to a lesser extent tourism and small business. The least affected was industry was residential real estate. The research focuses on each of these sectors accordingly.

## PREVIOUS STUDIO RESULTS FOR DARIEN

In the Fall of 2012, an earlier graduate studio from Georgia Tech's City and Regional Planning program, led by Dr. Larry Keating and Dana Habeeb, partnered with the Georgia Conservancy to study communities along Georgia's coast and investigate the potential impacts of SLR, specifically focusing on vulnerable populations and communities. The study area of this report included Chatham County, Liberty County, and McIntosh County. The research of the studio provided the building blocks for the current study of the economic impacts of SLR in Darien in McIntosh County and the Port of Savannah in Chatham County.

The previous report analyzed the impact of SLR on the Georgia coast over a 100 year period from 2010 to 2110, with the assumption that current economic conditions would continue over the study period. Keating and Habeeb used several different forms of modeling to determine the effects of SLR along the Georgia coast. First, they used the Skidaway Institute of Oceanography's hydro digital elevation bathtub model, estimating effects of a 1-meter rise in sea level on total land area. The researchers acknowledge that this model did not account for land cover changes such as wetland migration, which likely overestimates wetland losses.

In order to estimate the potential damage to physical structures, Keating and Habeeb used the Federal Emergency Management Agency's HAZUS data from the year 2000. The HAZUS data set divides buildings into seven broad categories: residential, commercial, industrial, agricultural, religious, education, and government. Within each category, the data set provides the number of existing buildings that would be impacted by SLR and an estimation of the structures' replacement value.

According to the studio's results, McIntosh County experienced the largest threat of flooding due to SLR among the studied counties with nearly 20% of residential land predicted to be inundated. Most of the impacted land in the county is concentrated in Darien.

Table 25 and Table 26 below display their results for the city of Darien.

**Table 25: Land Use-Total Acreage and Percent Inundation in Darien**

<b>Land Use</b>	<b>Total Acreage</b>	<b>Percent Inundated</b>
<b>Agriculture/ Forestry</b>	61.62	0.49%
<b>Commercial</b>	79.17	6.43%
<b>Industrial</b>	5.29	0.00%
<b>Parks/ Recreation/ Conservation</b>	313.15	87.63%
<b>Public/ Institutional</b>	45.83	0.00%
<b>Residential</b>	871.6	20.37%
<b>Transportation/ Communication/ Utilities</b>	221.95	0.50%
<b>Undeveloped/Vacant</b>	128.53	4.00%
<b>Total</b>	<b>1,727</b>	<b>29.09%</b>

Source: Keating & Habeeb, 2012

**Table 26: HAZUS- Number of Inundated Buildings and Replacement Value in Darien (Note: Replacement Values are X \$1000)**

	<b>Total Buildings</b>	<b>Inundated Buildings</b>	<b>Percent Inundated</b>	<b>Total Building Replacement Value</b>	<b>Inundated Building Replacement Value</b>	<b>Percent Inundated Value</b>
<b>Residential</b>	1,141	75	6.57%	\$101,599	\$10,003	9.85%
<b>Commercial</b>	55	4	7.09%	\$65,190	\$21,448	32.90%
<b>Industrial</b>	12	4	32.42%	\$7,508	\$2,983	39.73%
<b>Agriculture</b>	4	1	35.00%	\$1,032	\$408	39.53%
<b>Religion</b>	8	2	21.25%	\$10,502	\$5,253	50.02%
<b>Government</b>	8	2	23.75%	\$5,578	\$906	16.24%
<b>Education</b>	4	0	0.00%	\$4,342	\$0	0.00%
<b>TOTAL</b>	<b>1,232</b>	<b>88</b>	<b>7.13%</b>	<b>\$195,751</b>	<b>\$41,001</b>	<b>20.95%</b>

*\*Note: Calculations based on Skidaway Institute and 2000 HAZUS data*

*Source: Keating & Habeeb 2012*

According to the results from the Bathtub Model run by Keating and Habeeb, 29% of all land in the city of Darien is projected to be inundated due to SLR over the next 100 years. The majority of this land is currently classified as Park/Recreation/Conservation area. The residential land will experience the second most impacted with 20.37% inundation. The HAZUS model predicts that 75 residential buildings will be impacted, which accounts for 6.57% of all residential buildings in the city. Four commercial buildings and four industrial buildings are also expected to be impacted.

The team then conducted a Temporal Analysis of Darien. Some 62.9 % of Darien's total area of 21.2 miles will experience inundation. This inundation is particularly pronounced in the 15.8 square miles of wetland area with 85.9% or 13.6 square miles of inundation. Of the 1.8 acres of developed areas, 20.9% and 7 miles of primary roads are projected to be inundated.

As a one of the Georgia coast's most historically significant places, Darien could see impacts to some of its treasured historic sites as well. Loss of these assets are difficult to quantify, but Keating and Habeeb noted that historic structures like Fort King George in Darien, the nearby Hog Hammock Historic District, and the Sapelo Island Lighthouse are difficult to replace due to their cultural significance.



## LOCAL INDUSTRIES IN DARIEN

### COMMERCIAL FISHING

Commercial shrimping and fishing have long played a significant role in both the economic and cultural life of Darien (Coastal Georgia Regional Development Center 2007). Following the collapse of the timber industry from over-cutting in the 1920s, Darien's population turned to commercial seafood as a means of renewing growth in the city (Sullivan 2002). By the early 1960s, McIntosh County had the largest shrimping fleet in Georgia and boasted several shrimp and oyster packing houses in Darien (Sullivan 2002). At its peak, local fisherman report that Darien was home to some 60 shrimping vessels. In homage to the importance of this industry, Darien, since 1968, has hosted the Annual Blessing of the Fleet Ceremony to celebrate the tradition and promote Georgia shrimping.

Our analysis of the fishing industry in Darien is focused on the three largest fisheries (by tonnage) shrimp, crab and jellyfish (Graitcer 2012). A key support element for each of these industries is the wetland ecosystem found in the marshland of Darien. Already an area of concern due to the increasing development pressure on areas of deep water access and scenic marshland views, which may alter the functioning of coastal marshland ecosystems, the threat of SLR may compound these ecological impacts (Coastal Georgia Regional Development Center 2007). A Georgia Department of Natural Resources report estimates that since the late 1700's, more than 1.5 million acres of wetland have been altered. The State of Georgia now contains some 429,294 acres of these, nearly half of which (192,099 acres) are contained within McIntosh County, including 324 acres of wetlands within the developable area of Darien (Coastal Georgia Regional Development Center 2007).<sup>2</sup> Including the recently annexed Altamaha Wildlife Management area, which is primarily marshland, 68% of the land area of Darien is made up of coastal wetlands (Ecological Planning Group 2008). In fact, the Darien waterfront provides both scenic views of the marshland and docking space for local shrimping vessels, which, in turn, rely heavily upon shrimp populations which mature in the surrounding wetlands. These tidal wetlands serve an important role not only in providing vital habitat and feeding ground for numerous fisheries and aquatic species, but also "provide a storm surge buffer, prevent erosion, disseminate pollutants, and provide economic benefits to local and state governments" (Ecological Planning Group 2008).

The focus of this section is to see how SLR will affect the fisheries through the wetlands that play a crucial role as habitat, food source and nursery habitat for these species, as well as the direct impact of SLR on these species themselves. This research will lead to recommendations as to how the industry will be affected and how the people of that

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<sup>2</sup> The figure for the wetlands within Darien excludes the Altamaha Wildlife Management area, which is primarily wetland.

industry can best adapt to the changing conditions of SLR, in order to maintain a viable economy in Darien, consistent with its character.



**Figure 34: Darien Docks**

### Salinity and SLR

Salinity level, which refers to the concentration of salt in water, is an important feature of estuarine and wetland habitat. While salinity in open ocean remains notably constant at around 35 ‰ (parts per thousand), the salinity of estuaries and wetlands can vary significantly depending on the location within the estuary, the amount of fresh water flowing into the estuary, and the tides (NOAA). Though salinity levels are typically highest where the mouth of the river meets the ocean and lower upstream, salinity can vary as a result of the tidal cycle, with lower salinities in the spring due to melting snow and increased rainfall and higher in the summer as increased temperatures result in a greater amount of evaporation (NOAA). In particular, salinity can influence the amount of oxygen that is dissolved in water, with solubility falling as salinity levels rise (NOAA). As a result, salinity levels beyond a suitable range for species which live and breed in the wetland areas, “will negatively affect their growth and reproduction, and ultimately, their survival” (NOAA).

It is difficult to overstate the impact that salinity can have on marine species: “Salinity may be the most important factor affecting the distribution of estuarine organisms. It is an essential element in determining estuarine habitat and directly affects the distribution, abundance and composition of biological resources” (NOAA). A 2009 study of Georgia estuaries by Wiçski, Guo, Craft, and Pennings found that across salinity spectrum, ecosystem function in tidal wetlands change, and the richness of plant

species diversity decreases by as much as five times with increasing salinity (Więski et. al 2010). The study found that the biomass, height, and nutrient retention of aquatic plant life near the water's edge decreases from tidal fresh to tidal salt marshes (Więski et. al 2010). These aquatic plants, called Macrophytes, provide protection, oxygen, and a food source to fish and aquatic invertebrates, including shrimp and crab, in the tidal marsh ecosystems. The study's authors go on to suggest that SLR could trigger changes in plant distribution patterns with cascading impacts on wetland functions and services (Więski et. al 2010).

As a transitional area between land and sea, salt marshes are especially vulnerable to SLR and the resultant salinity changes (Simas et. al 2001). A 1999 study out of the University of Georgia found that, over the period from 1973 to 1992, surface salinity samples taken from the Savannah, Ogeechee, Altamaha, Satilla, and St. Mary's estuaries suggested a statistically significant decrease in discharge and increase in salinity in the Satilla and Savannah river estuaries. They also found a marginally significant decrease in discharge and increase in salinity and flushing time for the Altamaha River (Alber & Sheldon 1999). This study further cites "anecdotal reports that historic changes in salinity have already had an impact on the distribution of plants (e.g. wild rice) and animals (e.g. crabs) in these systems" (Alber & Sheldon 1999). While the study notes that the data collected could not distinguish the exact cause of these changes (be it changes in geomorphology, changes in local runoff characteristics, or direct groundwater input), it should not be discounted that the "observed increases in salinity could be the result of large-scale changes such as sea level rise or short-term increases embedded in a larger climatological cycle of rainfall and drought" (Alber & Sheldon 1999).

In the body of literature surrounding SLR, there is broad agreement that "sea-level rise will alter hydrologic patterns, resulting in changes in salinity intrusion dynamics along coastal rivers" (Water Research Foundation 2012). The variability of salinity is influenced by a number of factors, but especially stream flow, which is contingent upon precipitation and anthropogenic alteration of freshwater flow, and water-level conditions (Water Research Foundation 2012). These variations in salinity in turn, can greatly impact the characteristics of wetlands; a 2004 study by Higinbotham et al. concluded that marsh-type is more highly correlated with salinity than elevation when fresh-water flow is significant (Higinbotham et. al 2004). As a number of the current studies on the impacts of SLR are focused more broadly on predicting the impacts of climate change, it is common to calculate both for SLR and altered precipitation patterns.<sup>3</sup>

A 2009 study conducted by Craft et al. explored the susceptibility of the tidal marsh ecosystem to accelerated SLR and concluded: "Model simulations using the

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<sup>3</sup> See Water Research Foundation. Estimating Salinity Effects Due to Climate Change on the Georgia and South Carolina Coasts. 2012.; and Fisheries and Climate Change: Potential Challenges and Opportunities for Commonwealth Fisheries. Annette Sands - Australian Bureau of Agriculture and Resource Economics and Science. 2011.



Intergovernmental Panel on Climate Change (IPCC) mean and maximum estimates of sea-level rise for the year 2100 suggest that salt marshes will decline in area by 20% and 45%, respectively. The area of tidal freshwater marshes will increase by 2% under the IPCC mean scenario, but will decline by 39% under the maximum scenario" (Craft et. al 2009). The findings further suggest "that tidal marshes at the lower and upper salinity ranges, and their attendant delivery of ecosystem services, will be most affected by accelerated sea-level rise, unless geomorphic conditions (i.e. gradual increase in elevation) enable tidal freshwater marshes to migrate inland, or vertical accretion of salt marshes to increase, to compensate for accelerated sea-level rise" (Craft et. al 2009). Of specific relevance to this studio, for the Altamaha River in particular, "the model predicts a large decline in area of tidal freshwater marsh (-38%) and swamp (-24%), a smaller decline of salt marsh (-8%), and a small increase in brackish marsh habitat (+4%)" (Craft et. al 2009).

The distinction in these categories of marsh are important because the "results suggest that salt, brackish, and tidal freshwater marshes of the Georgia coast will respond differently to a 52-cm increase in SLR" and as (noted before) salinity ranges have a profound effect on the distribution of estuarine organisms (Craft et. al 2009). The decrease in the quantity of saltmarsh, attributed to submergence and replacement by tidal flats and estuarine open water may be particularly detrimental to shrimp and crab populations (Craft et. al 2009). The following sections examine the impact that salinity may have on various species, and analyzes the results of a SLAMM (Sea-Level Affecting Marshes Model) model run by the South Atlantic Migratory Bird Initiative (SAMBI), similar to that run in the Craft study in order to understand the progression of this marshland loss over time.



**Figure 35: Wetlands near Darien**

## Shrimp Fishery

Darien's largest commercial fishery is shrimping, with harvests of both brown shrimp<sup>4</sup> and white shrimp<sup>5</sup>. Each year, the DNR Commissioner opens offshore waters to commercial seafood shrimping on May 15<sup>th</sup> and it remains open until December 31<sup>st</sup>, provided that shrimp counts are 45 or fewer per pound (with heads on) (Georgia Department of Natural Resources 2013).<sup>6</sup> The legal hours for the commercial harvest of shrimp begin 30 minutes before official sunrise and extend to 30 minutes after official sunset (Georgia DNR 2013). The early part of the season (May and June) is dominated by the catching of white shrimp, with some commercial vessels going as far as North Carolina. As the season draws later, the shrimpers shift their catch to brown shrimp, which become available from June to August, before the white shrimp return towards the end of the season in December<sup>7</sup>. Wild-caught shrimp generate nearly \$12 million of revenue annually across the state (McLeod 2013).

The shrimp are caught using a method called trawling, where a boat (known as a trawler) trails one or more large nets (sometimes as wide as 200 feet) across the seafloor typically within 5 miles of the shore. The trawlers are operated by a captain and one to two crew members, depending on the size of the vessel. The shrimping crews go out on trips from 5 to 7 days at a time (according to the vessel's ability to carry enough fuel and ice), and in the past have brought in between 600-800 pounds (6 to 8 boxes) of shrimp at a time. In turn, these shrimp are currently sold for around \$6.50 a pound and are distributed across a wide range of geographic locations<sup>8</sup>.

Median salary for commercial fisherman in the United States is \$25,590 (Bureau of Labor Statistics 2013). In the last several years, Darien's shrimpers have suffered greatly. In 2013, shrimpers anticipated increased profits as the price per pound climbed more than a dollar due to import shortages.<sup>9</sup> However, conversations with commercial fisherman indicate that not only are they harvesting fewer shrimp, but the shrimp they do bring in are much smaller (Landers 2013). This season, local shrimpers in Darien have only been able to harvest 200-400 lbs (2 - 4 boxes), taking a significant toll on their profits after expenses. With gas prices rising to \$3.50 per gallon and boats consuming in excess of 150 to 200 gallons per trip, after paying crew members for a week's worth of work, repairing damaged nets, and purchasing ice to store the shrimp, expenses easily can climb into the thousands. For a larger shrimper, a trip may cost almost \$4,000. As a result, a once bustling shrimping industry in Darien has seen a fleet of almost 60 boats dwindle to between 20 and 30.<sup>10</sup> This trend is consistent with a state-

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<sup>4</sup> Farfantepenaeus aztecus

<sup>5</sup> Litopenaeus setiferus

<sup>6</sup> Interviews with fisherman indicate that some may begin as early as February with roe fishing, but this must be done beyond three miles out to avoid violation of state law.

<sup>7</sup> At the Commissioner's discretion the offshore waters may also be opened during January and February if the shrimp count is 50 or fewer per pound, with heads on.

<sup>8</sup> Information gathered through informal interviews with shrimpers in Darien.

<sup>9</sup> These shortages have, in turn, been brought on by disease in Thailand's shrimping ponds.

<sup>10</sup> Local Fisherman Interview by John Risher and Carrie Coburn. Darien, GA. September 28, 2013.

wide exodus from the industry which has seen the number of fishing boat licenses issued each year for shrimping fall from around 2,000 in 1979 to about 165 in 2013 (Landers 2013).

The most recent wave of declining profits are closely linked with steep declines in shrimp populations, driven by a devastating disease known as Black Gill. This was identified by multiple shrimpers interviewed in Darien as the biggest obstacle to good fishing. Black Gill is caused by a type of parasite, called a ciliate, that “attaches and penetrates the gills in the trophont stage” of the shrimp (South Carolina Department of Natural Resources 2012). According to the South Carolina Department of Natural Resources, the disease “impairs respiration, thus reducing the shrimp’s endurance. This may...make the shrimp more vulnerable to predators or temperature extremes” (SCDNR 2012). Black Gill starts in August and usually subsides around December. In 2013, nearly 90% of shrimp caught in some trawls have been infected (McLeod 2013). In September, shrimpers in South Carolina caught 44,000 pounds of shrimp, just 6% of the 750,000 pounds that they had caught in the same month a year earlier (McLeod 2013). The situation is only slightly improved in Georgia where in August, September, and October shrimpers have pulled in less than half of their average haul (McLeod 2013).

Between 1998 and 2002 the Southeast experienced record breaking drought and saw increasing incidence of saltwater intrusion along the Georgia and South Carolina coasts, causing some to speculate that high salinity may be to blame (Water Research Foundation 2012). With record high rainfall and frequency of the parasite only climbing, wildlife experts have begun to explore the possibility that too much change in water salinity upset the balance of fresh and salt waters, stressing shrimp, and leaving them vulnerable to the parasite (McLeod 2013). Local shrimpers also reported hearing from wildlife experts about a relationship between outbreaks of the disease and fluctuating salinity levels. Additional research is needed to understand this parasite’s life cycle and the environmental factors causing its proliferation in some years but not others (Water Quality in Georgia 2006-2007 2008).

Complicating the understanding of the role of Black Gill is the fact that shrimp populations can undergo dynamic stock fluctuations from year to year. When temperatures drop to the low 40s, the cold can kill over-wintering shrimp in the estuaries (Stepzinski 2011). White shrimp, being a subtropical species, tend to be more susceptible to large stock fluctuations than do brown shrimp populations (SCDNR 2012). While the larger white shrimp migrate as far as south as Cape Canaveral, Florida, most are caught before they are able to migrate back (SCDNR 2012). Thus, the primary spawning stock are smaller white shrimp that over-winter in the estuaries (SCDNR 2012). In December of 2010, DNR coast-wide sampling of shrimp showed a population 11% larger than the long-term average (Stepzinski 2011). By February of the next year, following an especially cold winter in which temperatures dropped to lethal levels, coast-wide sampling catches of shrimp were 95% below the average populations (Stepzinski 2011).

While the exact cause of this declining population, its relation to Black Gill, and the cause of Black Gill merit additional exploration, we are seeking to understand the role that SLR and the subsequent changes in salinity of the wetland nurseries may play in the industry's future. To this end, an understanding of the shrimp's reliance on estuaries and wetlands may prove helpful. Howe, Wallace and Rikard offer this concise explanation of the penaeid shrimp life cycle:

*“The life cycles of penaeid shrimps include offshore spawning, oceanic larval development [as planktonic larvae], and migration into estuaries as postlarvae after being transported to coastal areas by surface ocean currents [where they remain for two to three months until they are about four inches]. The timing of postlarval shrimp movements into estuaries appears to be species specific. Brown..., pink..., and white ... shrimp are typically found in estuaries in greater abundance during the spring, winter, and summer, respectively. Once in the estuaries, rapid growth is followed by migration of subadults to the open ocean where their life cycles are completed” (Howe et al. 1999).*

Within the estuaries, post larval shrimp migrate into the shallow waters at the upper ends of the saltmarsh tidal creeks (SCDNR 2012). The shrimp concentrate in the creek beds, traveling into the marsh grass to feed at high tide (SCDNR 2012). As they grow, smaller shrimp remain in creek beds feeding on plant and animal organic materials at the bottom, while larger juvenile shrimp move into the deeper creek waters (SCDNR 2012). The shrimp grow as much as 2.5 inches per month while in the estuaries, molting several times per week with decreasing frequency as they grow (SCDNR 2012). Upon reaching about 4 inches in length, shrimp gradually move towards higher salinity levels in the coastal rivers and ocean (SCDNR 2012). These coastal rivers allow for some additional growth while the shrimp move into the “lower reaches of sounds, bays, and river mouths”, which serve as a “staging area” for population accumulation, prior to the final migration into ocean waters (SCDNR 2012). During periods of large populations, the shrimp will migrate into the ocean at lengths of 4 to 5 inches, but when stocks are small, they may remain in the estuaries until they are more than 6 inches (SCDNR 2012). Once in the open ocean, most shrimp will die before reaching nine months of age (SCDNR 2012).

A growing body of literature has begun to explore the impacts of salinity and temperature on shrimp growth, maturation, reproduction, and mortality. According to the South Carolina Department of Natural Resources, the “ideal nursery habitat has brackish water that is about 25 to 40 percent sea water [about 9 to 14‰<sup>11</sup>] for white shrimp and 35 to 65 percent sea water [about 12 to 23‰] for brown shrimp,” though they can survive in higher and lower salinity levels (SCDNR 2012). Beyond the size of the shrimp population that survived the previous season to spawn and water temperature, the most important factor influencing shrimp abundance is the salinity of the nursery habitat (SCDNR 2012). A 2001 study in France found mortality was higher

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<sup>11</sup> This symbol denotes parts per thousand of salt.



for brown shrimp at 5 ‰ salinity than at higher salinities, females raised at 25‰ salinity started to become ovigerous (bearing eggs) after 32 days as oppose to 80 days for those females held at 15‰, brackish salinity (15‰) would delay ovarian development as opposed to higher salinities, and low salinities (5‰) inhibited maturation (Gelin et al. 2001). Similarly in a 2003 study, when a 4-week growth trial was conducted with juvenile brown shrimp at 2‰, 4‰, 8‰, and 12‰, shrimp maintained at 8‰ and 12‰ grew significantly more than shrimp maintained at 2‰ and 4‰ (Saoud & Davis 2003). One study by Wang and Chen explored the immune response of white shrimp<sup>12</sup> at differing salinity levels. When injected with *Vibrio alginolyticus*, a bacteria known to infect commercial farmed shrimp with devastating effects, mortality began to occur within six hours for shrimp held at 5‰ and 15‰ and was significantly higher than for shrimp held at 25‰ and 35‰ (Wang & Chen 2005). After four days, the total mortality was found to be the lowest at 25‰ and highest at 5‰ (Wang & Chen 2005). Further it was concluded that change in water salinity can trigger disease outbreak (Wang & Chen 2005).

There is however, still some debate in the literature. A 1996 study conducted by Zoula Zein-Eldin found that growth rate did not differ significantly among shrimp<sup>13</sup> held at 2, 5, 10, 25, or 40‰ (Zein-Eldin 1996). A study one year later, by Ponce-Palfox, Martinez-Palacios, and Ross, concluded that survival and growth rate of postlarvae white shrimp<sup>14</sup> were dependent not only on temperature and salinity, but also on the temperature-salinity interaction. The results showed that higher salinity had a negative correlation with growth and survival only at higher temperatures and salinity of 20‰ (the low salinity range of the study) appeared to have a negative impact on growth and survival at temperatures greater than 25°C (Ponce-Palfox et al. 1997).

One final note on the shrimp fishery relates to the rapid rate of land development along the coastal southeastern United States, which has been a growing topic of concern for fisheries management. According to a study concerning grass shrimp<sup>15</sup> conducted by Porter et al., “adult grass shrimp abundance is depressed in urbanized estuary compared to pristine estuary (1997). In fact, in Murrells Inlet, South Carolina, streams adjacent to residential or commercial development contain the lowest density of grass shrimp, in some cases serving as near “estuarine deserts – stream reaches void of adult grass shrimp” (Porter et al. 1997). Though of a different species than the brown or white shrimp, these grass shrimp results suggest a potential environmental impacts on commercially fished shrimp species as well, or at the very least, an area worthy of further scientific exploration.

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<sup>12</sup> *Litopenaeus vannamei*

<sup>13</sup> Both *P. setiferus* and *P. aztecus*

<sup>14</sup> *P. vannamei*

<sup>15</sup> *Palamonetes pugio*



**Figure 36: Boats at Darien Docks**

## Crab Fishery

The 2<sup>nd</sup> largest fishery in Darien is the blue crab fishery. The season for blue crabs in Georgia is year round, but most often the crabs are caught in the summer and beginning of fall (Van Den Avyle 1984). Female crab carrying eggs, called sponge crabs, are common from April until September and are protected from harvest by law (Whitaker 2010). While earlier stages of development, the zoea larval and megalopal, take place off shore, the megalopae begin a migration into the saltmarsh creeks (Whitaker 2010). Within the estuarine nursery habitat, the megalopae transforms into the juvenile crab (Sartwell 2009). The preferred habitat for blue crabs is “tidal salt marsh estuaries, typically with...moderate salinities” (Cooley 2003). This optimal range is between 20.1-31.1‰ for larval stage, and 22-28‰ salinity is required for “normal hatching of eggs and for normal development of zoeae.” Following the zoeae, megalops, and juvenile stages, however, the salinity range for adults is much wider so as to accomodate the high salinity ocean waters encountered in the later stages of its life cycle (Whitaker 2010). Young crabs thrive in years of increased freshwater in the system as it brings more nutrients while decreasing the salinity levels (Whitaker 2010). Water temperature is also essential factor for the development of crab, with optimal levels being found between 21-30 degrees Celsius (Van Den Avyle 1984).

The females migrate into the higher salinity levels of the mouth of the estuaries or ocean to spawn, reinitiating a cycle in which only about one of every one million eggs will survive to adulthood (Whitaker 2010). The majority of crabs stay within one estuarine system for their life and most live less than one year (Van Den Avyle 1984).

Historically, Georgia's crabbers have experienced the consequences of changes occurring in the habitat of the blue crab. The most poignant example of this can be seen with the parasite, *Hematodinium*. In this example, a drought in the state caused a 45 year average of 8.6 million pounds of crab a year in catch to fall to 1.8 million pounds. This parasite was not formerly unknown, but because of the crabs' needs for specific water conditions in terms of salinity the effect of the drought was severe:

*“During a drought, less fresh water comes down the state's rivers to mix with salt water that tides bring in from the Atlantic Ocean. This raises the salt content in coastal estuaries. And it is in water with this higher percentage of salt that *Hematodinium* thrives and spreads from crab to crab. Lee and Frischer found a direct correlation between the state's recent drought and the prevalence of the disease in the state's blue crab population. They also cite data showing that during times of high river flow, when the percentage of salt in the estuaries is lower, blue crab landings historically have increased” (Science Daily 2003).*

## Cannonball Jellyfish

Cannonball jellyfish make up the third largest fishery by tonnage caught in Darien (Landers 2011). They are especially abundant in the waters of Georgia and South Carolina, often appearing near the coasts and in the mouths of estuaries (Whitaker et al. 2010). Among the least venomous of jellyfish, the cannonball jellyfish rarely exceed 8 – 10 centimeters in diameter and have no tentacles (Whitaker et al. 2010). While adult

jellyfish do have control over vertical movement, they are largely dependent on currents, tides, and winds for horizontal movement (Whitaker et al. 2010). Living in estuarine and saline water, they can tolerate a range of salinity from 17.7 to 36.5 ‰. The Department of Natural Resources for South Carolina advises us to consider that these jellyfish fisheries have been decreasing in population in Asia, and that extend catching within this fishery “must take into account how the increased fishing would impact their overall role in the food web and their impact on leatherback sea turtles,” as they are the main source of food for that species. According to those experienced with Darien’s waters, jellyfish are highly abundant and still a nuisance when they are caught in trawling nets instead of shrimp (Griffin et al.).

Long a nuisance to fisherman, jellyfish are a relatively new industry being introduced to Darien just two decades ago when George Tai began catching and exporting the jellyballs (as they are colloquially known) to Asia (Graitcer 2012). The jellyballs are dried (losing 80 to 90 percent of their weight), preserved, and sold to distributors in Japan, Thailand, and China, where they are marketed as a delicacy (Graitcer 2012). Jellyballs are seasonally fished during the late winter and spring, while the shrimp industry is out of season and, thus, serve as a key fishery to bridge seasons for some shrimpers (Graitcer 2012). These jellyballs can fetch between \$0.06 and \$0.08 per pound and, therefore, must be harvested in very large quantities.<sup>16</sup> Currently there are 5 boats that harvest jellyfish in Darien and sell their catch to Marco Seafood, the regions only jellyfish processor and exporter. This number is limited by Marco Seafood’s capacity of only about 60,000 pounds (approximately one to two boat loads) at a time (Landers 2011). Interviews with local fisherman revealed that a few additional vessels also engage in the industry by selling their harvests to a west coast processing facility<sup>17</sup>. In order to capture the jellyballs, nets are pulled slowly through the middle and upper parts of the water column for a period of about twenty minutes (Landers 2011). While officially recognized as an experimental fishery by the Georgia Department of Natural Resources in 1998, in federal waters, just three miles off the coast, it is not a recognized fishery and, therefore, largely free from regulation (Landers 2011).

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<sup>16</sup> Local Fisherman Interview by John Risher and Carrie Coburn. Darien, GA. September 28, 2013.

<sup>17</sup> Local fishermen Interview by John Risher and Carrie Coburn. Darien, GA. September 28, 2013.

## SLAMM Model

The SLAMM (Sea Level Affecting Marshes Model) model “simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise” (Clough et al. 2010). The model was first designed in the 1980s with EPA funds and has since been improved over six versions and been utilized to project the impact of SLR on geographies as diverse as the Puget Sound, San Francisco Bay, Delaware Bay, and the South Carolina and Georgia coasts (Clough et al. 2010).

While the results of the model run by Craft et al. prove useful in understanding the projected change in marsh habitat over the next century, data by decade was not included in the publication nor made publicly available. A 2007 report by the Water Research Foundation, titled *Estimating Salinity Effects Due to Climate Change on the Georgia and South Carolina Coasts*, found that in both the Lower Savannah River and Grand Strand region estuarine systems, “the relationships between sea level, freshwater streamflow, and salinity intrusion are complex and nonlinear”. A decade-by-decade analysis, however, was carried out by the South Atlantic Migratory Bird Initiative (SAMBI) in order to provide a clearer understanding of the potential impacts of SLR on the wetland habitat. Our team used this SAMBI output data to better understand how sea level rise will impact Darien’s commercial fishing industry.

## Methodology

Drawing on a number of sub-model inputs including inundation, erosion, over-wash, saturation, salinity, and accretion, the SLAMM Model incorporates geometric and qualitative relationships into a complex decision tree across sites divided into equally sized cells of 5 meter to 30 meter, depending on the input-data available (Clough 2010). Relative SLR is “computed for each site for each time each step” and outputs are classified into 23 land categories derived from the National Wetlands Inventory (NWI) and summarized in tabular and graphic form (Clough 2010). The model is also capable of incorporating dikes and other forms of anthropogenic modification that affect the ability of wetlands to migrate, documenting that information in the NWI data layer (Clough 2010). Finally, the model incorporates IPCC (Intergovernmental Panel on Climate Change) projections and fixed rates of global sea level rise, correct[ing] for long-term differential between local and global effects using local tide gauge trends (Clough 2010).

In the event of inundation and erosion, the model predicts changes from one type of land cover class to another. The calculations are based on a complex set of inputs over times, but the broad shift from one class to another is detailed in the table below.<sup>18</sup>

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<sup>18</sup> It is important to note the salt marsh (titled regularly flood marsh in the table) is converted through increased inundation on the scrub-shrub/transitional marsh land cover category. This transitional marsh, in turn, can result from inundation to swamp, inland fresh marsh, and tidal fresh marsh land cover types. Inundation of salt marsh, however, results in conversion to tidal flats.

**Table 27: Model Relationships**

	<b>Inundation:</b> <i>Non-adjacent to open water or Fetch &lt; 9km (non tropical systems)</i>	<b>Erosion:</b> <i>Adjacent to Open Water and Fetch &gt; 9km (erosion)</i>
Converting From	Converts To	Converts To
Dry Land	Transitional salt marsh, ocean beach, or estuarine beach, depending on context (see below)	Erosion of dry land is ignored.
Swamp	Transitional salt marsh	Erosion to Tidal Flat
Cypress Swamp	Open Water	Erosion to Tidal Flat
Inland Fresh Marsh	Transitional salt marsh	Erosion to Tidal Flat
Tidal Swamp	Tidal Fresh Marsh	Erosion to Tidal Flat
Tidal Fresh Marsh	Irregularly Flooded Marsh	Erosion to Tidal Flat
Scrub-Shrub, Irregularly Flooded Marsh	to Regularly Flooded Marsh	Erosion to Tidal Flat
Regularly Flooded Marsh	to Tidal Flat	Erosion to Tidal Flat
Mangrove	to Estuarine Water	Erosion & Inundation to Estuarine Water
Ocean Flat	to Open Ocean	Erosion to Open Ocean
Tidal Flat	<u>Erosion</u> , Inundation to Estuarine Water	Erosion to Estuarine Water
Estuarine Beach, Ocean Beach	open water	Erosion to open water

Source: Clough et al. 2010

### The SAMBI SLAMM Model

Conducted as part of the Designing Suitable Landscapes for Bird Species in the Eastern United States project, the SAMBI SLAMM model provided data output in 10 year increments to 2100 for much of the coastal area from southern Virginia to northern Florida (SAMBI). While the model was run for four sea level scenarios (A1B, A2, B1, and A1FI), for our analysis we have focused on the A1B scenario results, which describe “a future world of very rapid economic growth, global population that peaks in the mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies ... [and energy production is] balanced across all sources (fossil and non-fossil intensive)” (Clough et al. 2010). The A1B global SLR scenario predicts 694 mm of rise by 2100, about 30% lower than the 1-meter SLR projections used in this studio. The SAMBI model further selected the “protect development” option, which represents further construction of dikes around all developed areas.



**Table 28: Sea Level Changes in SLAMM Model**

Model Maximum - Total sea level change (mm)				
Year	A1B	A1FI	A2	B1
1990	0	0	0	0
2000	29	29	29	29
2010	63	65	64	64
2020	103	110	104	105
2030	153	164	149	151
2040	214	228	204	203
2050	284	299	269	259
2060	360	375	343	319
2070	442	453	430	381
2080	527	529	526	444
2090	611	602	631	507
2100	694	671	743	567

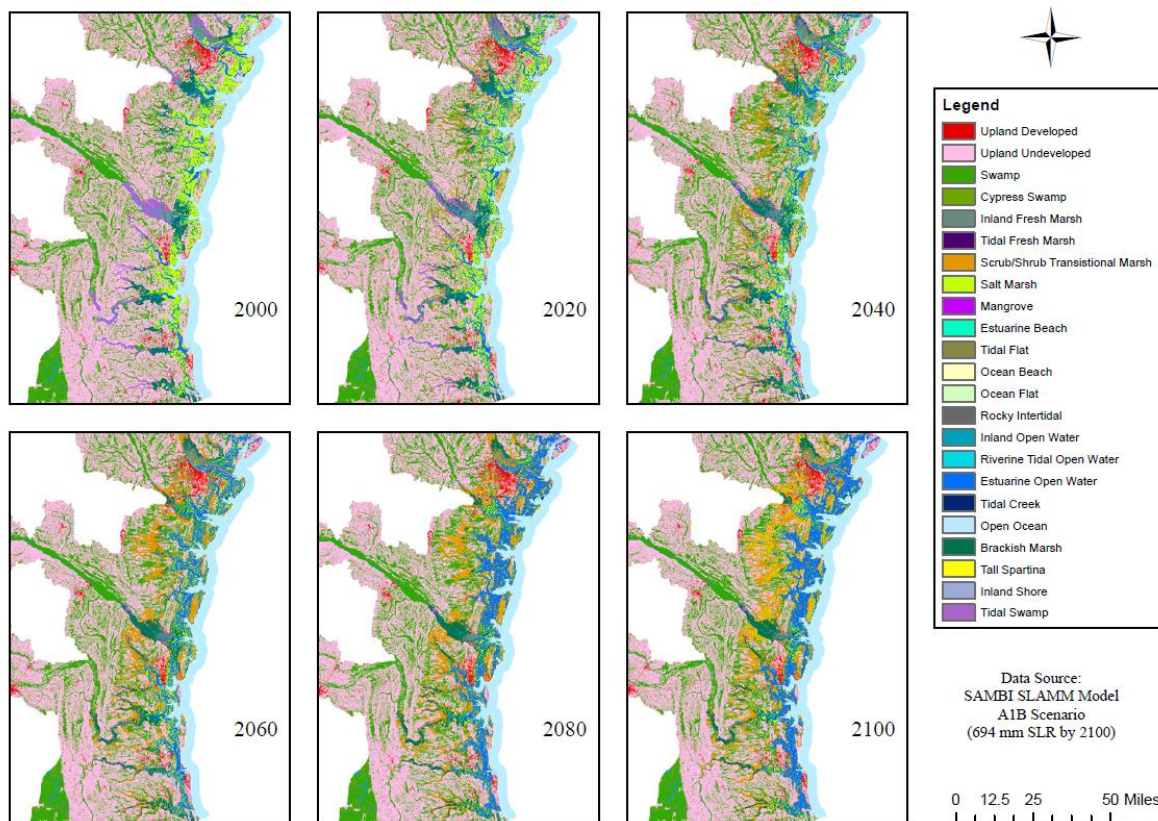
Source: <http://www.ipcc.ch/ipccreports/tar/wg1/553.htm>

### Using the SAMBI SLAMM Data

The SAMBI SLAMM data, made available as raster GIS data sets, were clipped to only account for wetlands within 17.3 miles of the Georgia coast, based upon an estimated top speed of shrimping vessels of 15 knots (17.3 miles per hour). Though some shrimping vessels travel as far as North Carolina in the early season, it seems likely that the shrimping and crabbing industries would relocate to other states to be nearer the populations of commercially fished species if Georgia's estuaries failed to produce adequate supplies of these species. Further, while large white shrimp have been known to migrate far from their nursery habitats in the winter, the South Carolina Department of Natural Resources tagging studies have indicated that these shrimp are typically harvested during this migration and that the spawning stock over-winters in the local estuaries. Similarly, most blue crab also stay within a single estuary for the duration of their life. In an effort to best understand the economic impact of SLR on commercial fisheries, we have limited our data to only account for wetlands accessible within one hour of the Georgia coast.



## SLAMM Model Results



**Figure 37: SLAMM Model of Georgia Coastal Habitat 2000 - 2100**

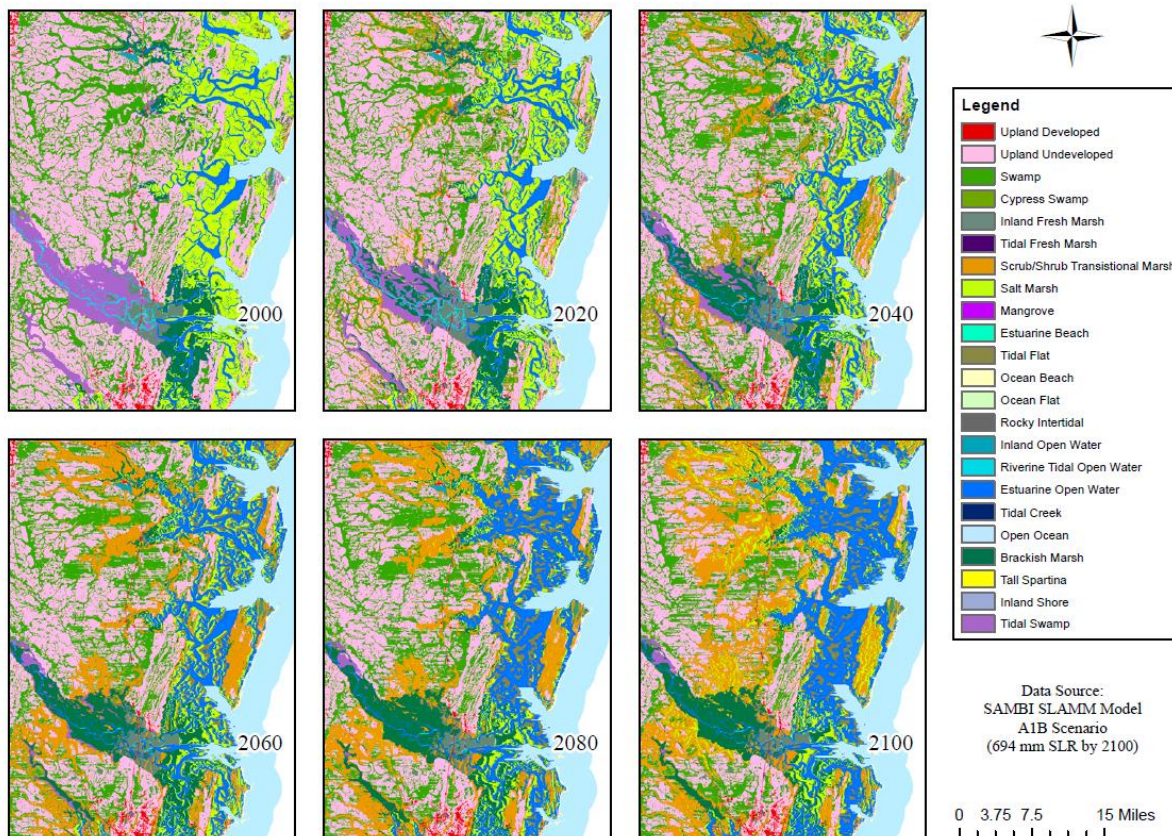
The SAMBI SLAMM model of the Georgia coast line suggested that significant changes are in store for salt marsh habitat over the next century. By 2100, the model predicts a 50% reduction in the amount of salt marsh, from 1322.25 to only 661.09 square kilometers. Looking at the data by decade, however, reveals a larger trend in which salt marsh steadily decreases until reaching a low of 511 square kilometers in 2080, a loss of a full 61% of salt marsh habitat, before rebounding over the next 20 years. This rebound, in turn is driven by the abundance of new transitional marsh created over that period. The quantity of transitional marsh grew every decade except one in the model, expanding from just 25 square kilometers in 2000 to over 1500 in 2100. These results were roughly consistent with previous studies (see Simas et al. 2001, Shenker 2009, and Craft et al. 2009).

While the salt marsh (also termed regularly flooded marsh in the SLAMM technical literature) is of primary concern due to its value as shrimp and crab habitat, other land cover classifications may also play an important role in the health of these fisheries. The Wiçski et al. study suggests that “plant diversity, primary production, and nutrient recycling ecosystem functions of tidal fresh and brackish marshes exceed those of salt marshes” (Wiçski et al. 2010). Further, these habitats have historically been heavily impacted by agricultural activities and, thus, account for significantly less land area than

do salt marshes (Więski et al. 2010). Consequently, the authors hold that fresh and tidal marshes should be considered equally important conservation targets to salt marsh. While tidal marsh do account for a significant component of the overall distribution of land cover categories, making up less than a square kilometer of land area in the model, inland fresh marshes experience a period of marginal growth in the first half the century, followed by a steady decline which reaches an 18% aggregate decrease by 2100.

While the SLAMM model offers some indication of the types of changes that may occur along Georgia's coastal marshes, there are several limitations to the model that are important in gauging its usefulness. Accretion rates in the model are not affected by fresh water flow (Clough 2010). Further the model does not contain a detailed bathymetrical model, resulting in a linear salinity component and the tidal effects on estuary geometry not being predicted (Clough 2010). The overwash component contains a high degree of uncertainty with the frequency and magnitude of storms (Clough 2010). The model further lacks feedback mechanisms that can factor into accelerating SLR, for example, as indicated by Craft et al., "increasing inundation of salt marshes may increase macrophyte production and lead to increased vertical accretion" (Craft et al. 2009). Further, limitations with the input data, such as lower resolutions, may carry forward into the model (Craft et al. 2009). Finally, the model lacks a concept of "marsh health", as marsh-types migrate inland basis of salinity and elevation and do not account for other ecological features (Clough 2010).

## Implications of Research



**Figure 38: SLAMM Model of Glynn, McIntosh, and Liberty Counties 2000 – 2100**

Commercial fishery species have been subjected to overfishing, habitat destruction, alteration of river flow regimes, and pollution, affecting the fisheries health for some time (Shenker 2009). The scientific literature indicates that rising salinity levels will have both direct and indirect impacts on the health, growth, reproduction, and survival of two of Darien's largest commercial fisheries, affecting both shrimp and crabs. Further, the studio's model clearly demonstrates significant changes in the available habitat along the Georgia Coast. With these additional stresses of sea level rise, the importance of maintaining the health of the wetlands has only grown.

A body of research exists to suggest that shifts in environmental conditions have a strong correlation with the spatial distribution of fish and aquatic invertebrates (Sumalia et al. 2011). The changes in spatial distributions could affect fishing travel times, which in turn could bring about change in the harvest levels as well as fuel and ice consumption. As much of the current fishing fleet is comprised of larger vessels, consuming larger quantities of fuel, such shifts in spatial distribution leading to uncertainty in harvest expectations and increased fishing costs may prompt a move to smaller, more fuel efficient vessels (Sumalia et al. 2011). More technologically advanced fleets may be better prepared to adapt to sea-level rise by shifting to other fishing grounds, changing gear, and targeting different species (Sumalia et al. 2011).



Even without the stresses of overfishing, habitat destruction, pollution, and salinity changes associated with sea-level rise, the commercial fishing industry in Darien faced a significant hurdle in competing with Asian and South American shrimp and prawn farms, which cheaply cultivate shrimp and other seafood for human consumption. The emergence of these imported shrimp in the 1990s led to a steep decline in the price per pound. Rising fuel costs, increased regulation, and unpredictable annual harvests have led dozens of commercial fisherman to exit the industry over the last several decades. The black gill epidemic of the past several years and the economic struggles of shrimpers associated with it may provide an early glimpse into a future of decreased financial feasibility for the industry. These impacts will undoubtedly carry through to Georgia consumers, who may find decreased availability and increased costs associated with purchasing wild-caught Atlantic shrimp.

Due to the uncertainties and limitations noted above, we have opted to refrain from estimating direct monetary impacts from the wetland losses indicated in the SLAMM Model. A number of other studies in the past, however, have attempted to quantify the value of goods and services provided by the ecological functions of wetland habitat. A study published in *Nature* in 1997, for example, which estimated economic value of 17 ecosystem services (such as storm protection and flood control) across 16 biomes, including both swamps and tidal marshes, found that wetlands account for \$14,785 of economic production per hectare per year (Costanza et al. 1997).<sup>19</sup> Of this number, habitat, food production, recreation, and cultural value accounted for a modest \$304, \$256, \$574, and \$881 respectively (Costanza et al. 1997). Much greater economic impact was attributed to disturbance regulation such as flood prevention (\$4,538), storage and retention of water (\$3,800), and waste treatment and pollution control (\$4,177) (Costanza et al. 1997). Wiçski et al. are quick to note, however, that all wetlands "are not the same, and many do not provide the same levels of ecosystem functions" (Wiçski et al. 2010).

Historically, Darien has faced a need to shift its economy before. Once heavily focused on a timber industry, Darien shifted to reliance upon oysters until overharvesting forced yet another shift to shrimping and crabbing. Such a change may be yet another inevitable outcome of sea level rise. Some local commercial fisherman have already begun to adapt to this need, focusing on snapper, grouper, clams, and other less impacted species. The key is understood to be flexibility based upon catch limits, which in turn rely upon the health of the fishery. The limitations to this approach are the high cost of licensing and equipment, as well as specialized expertise to each commercial species.

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<sup>19</sup> Estimates in the study were created through a synthesis of a number of previous studies based on a variety of methods; however, many of the valuation techniques are directly or indirectly based on the 'willingness-to-pay' of individuals for various ecological services. Values are provided in 1994 dollars.

## Tourism

Tourism is one of the world's largest industries, spanning many different sectors including restaurants, lodging, recreation, retail, real estate, car rentals, etc. (Tourism Satellite Account 2012). This makes quantifying the impacts of tourism challenging. Economic impacts from tourism can be seen through business revenues, employment, government tax revenue, distribution of income, and the use of public goods (Frechtling and Smeral 2010). The industry's broad reach touches many types of stakeholders, including private residences, public officials, business owners and managers, and employees of tourism establishments. The coastal tourism industry is very dependent on sensitive environments, and proper management of environmental tourism areas are important to yielding economic benefits.

Coastlines have long been magnets for tourists, but increasing development has caused governments to place more emphasis on sustainable development in tourism areas (Jennings 2004). The direct and indirect economic impacts of climate and environmental change will have a significant impact on many types of tourism, particularly heritage tourism and ecotourism (Tisdell 2003). This is very relevant for the state of Georgia. According to the Georgia Department of Economic Development, tourism is the second most important industry in the state, with 405,000 or 10.2% of all jobs in the state directly or indirectly sustained by tourism activities in 2012 (TSA 2012). Tourism in Georgia also generated \$2.8 billion in state and local taxes and \$3.6 billion in Federal taxes (TSA 2012). The Bureau of Economic Analysis reported that 8 million US jobs were related to tourism, including 5.7 million direct tourism jobs, and 2.3 million indirect tourism jobs in the second quarter of 2013 (BEA 2013).

Rising sea levels could severely impact coastal businesses, resorts, and historic areas. Since tourism impacts so many sectors of the economy, decreases in tourism related businesses would have far reaching effects. To better understand the impacts of Sea Level Rise on tourism, the studio team looked to both global and domestic examples.

### SLR & Tourism: Worldwide Examples

Sea Level Rise is a global issue that is being studied in all areas of the world. Many areas are studying the anticipated impacts that rising sea levels will have on tourism. Some of the studied areas include Ghana, the Caribbean, the southern United States, and coastal Australia. One study reported that sea level measurements indicate an average SLR of 3.3 mm/year, while showing the shoreline eroded by as much as 0.86 m/year between 1974 between 2005 (Sagoe-Addy 2012). Predictions for Ghana showed 10 cm, 23.4 cm and 36.4 cm sea level rise for 2020, 2060 and 2100 respectively with 1990 as base year (Sagoe-Addy 2012). These statistics show that many of Ghana's coastal tourist facilities will be inundated by the year 2100.

In South Florida, a 60 cm sea level rise is expected to erode beaches in South Florida, with the costs of beach re-nourishment ranging from \$1.7 to \$8.8 billion. As the Port of Savannah section demonstrated, SLR may also increase the impact of major storms, a particular challenge for hurricane-prone Florida. For example, Hurricane Georges in September 1998 resulted in revenue losses of approximately \$32 million in the Florida

Keys (Hall & Higham 2005). In Louisiana, the cost of protecting the city of New Orleans over the next 50 years is expected to be \$14 billion as the city is expected to go from 2.4 meters below sea level to between 3.2 meters and 3.8 meters below sea level. A report by the California State Parks Division forecasts major economic impacts in California due to the impact of SLR on tourism and natural habitats (King, McGregor & Whittet 2009). Additionally, they found that economic risks and responses would vary significantly depending on what part of the coastline one looks at. For example, Torrey Pines State Beach is estimated to suffer to \$5 million in damages caused by a 100-year coastal flood, and \$99 million in tourism spending and local and state tax losses caused by a narrow and eroded beach.

Low lying areas will be deeply impacted. In “The Vulnerability of Caribbean Coastal Tourism to Scenarios of Climate Change Related Sea Level Rise”, an estimated 29% of resorts will be fully or partially inundated by one-meter SLR; 49% to 60% of resort properties will be at risk of beach erosion (Scott, Simpson, & Ryan Sim 2012).

Unfortunately, many smaller tourist locales will be underprepared due to the lack agreement over the impacts of SLR. In North Carolina, the coastal counties generate billions of dollars a year, and have been the destination for up to 150% growth in the state’s population. However, they have not taken the steps like Virginia Beach and Myrtle Beach to protect their shoreline through strategies like shoreline hardening and beach re-nourishment.

### **SLR & Tourism: Darien**

Tourism is often the preferred economic development strategy for many rural Georgia communities. Special interest tourism such as nature-based tourism and heritage tourism have seen significant growth in the state. The Georgia Department of Economic Development reports that Georgia is in the top 10 states in the country in heritage tourism. Darien’s historic background, beautiful natural surroundings, and proximity to several sites listed on the National Register for Historic Places makes it an ideal spot for both heritage and nature based tourism. This is an important economic driver for this community.

In 2012, the Georgia Department of Economic Development reported that tourism supported 130 jobs in McIntosh County. During that same year, there was \$12.9 million generated in direct tourism spending, \$450,000 in state tax revenues and \$370,000 in local tax revenues (GDEcD Impact of Travel on Georgia Counties 2012). From 2011 to 2012, there was a 6.7% increase in direct domestic spending, a 3.1% increase in payroll, a 2.6% increase in employment, a 5.9% increase in state taxes, and an 8.8% increase in local taxes in McIntosh County (GDEcD Impact of Travel on Georgia Counties 2012). For a county with a 10.4% unemployment rate, any disruption to the 130 jobs related to tourism would be very significant for the community.



**Figure 39: Tabby Ruins in Darien**

The City of Darien uses its historic and cultural resources to attract around 25,000 tourists every year (Darien Visitor Center 2013). These resources give visitors a sense of Darien's unique identity and help tell the story of its heritage. Darien was the second settlement established by the British in the American colonies, providing a fascinating historical heritage. Fort King George is the most popular tourist destination in Darien. It was originally established as a military outpost on the delta of the Altamaha River in 1721. In the 1930s, remains of the Fort were discovered, and between 1988 and 2000, historical replicas were made to help visitors recreate the experience of the original Fort (The Times-Union). Today, the 25-acre site hosts monthly historical reenactments that are both entertaining and educational to visitors. In 2011, the site received 11,182 visitors. Approximately 75% of these were families, primarily visitors from the Savannah and Jacksonville regions and travelers along I-95 seeking respite from their drives (Fort King George 2012). In the future, Fort King George plans to offer more activities for tourist, such as canoe trips and camping tours. Various environmental organizations understand the cultural importance of these areas and have pledged their assistance and support in future development of the Fort.

Attracting heritage tourist is advantageous for the entire region. According to the Georgia Department of Economic Development, Heritage Tourists are typically more generous in their spending. On average, visitors to historic and cultural sites spend about \$62.00 more per day than other types of visitors and they are more likely to spend their money on antiques, art, gourmet foods, wine, health food, and outdoor experiences such as biking, hiking, canoeing, and bird watching (GDEcD Tourism



Resource Report 2011). Significant revenue comes from coastal activities and boat tours through the scenic marshlands. There are many other sites for tourist in the region including the Butler Island Rice Plantation, the Coastal Heritage Trail, and the Colonial Coast Birding Trail, which run along the coast of Georgia.



**Figure 40: Darien Docks**

Darien is also the launching point for a variety of coastal tours. Altamaha Coastal Tours, a local Darien company, offers kayaking, canoeing, camping and biking. They receive about 700-800 visitors per year, and they are one of the more popular attractions in Darien<sup>20</sup>. They offer tours from Darien to the Blackbeard Island Wilderness area, Lewis Island, and other offshore nature preserves. Another local business owner, Captain Phillip offers River Boat Tours, where visitors learn local history, the ecology of the area, and are able to bird-watch.

Darien's scenic waterfront and historic downtown area is a popular attraction for visitors. Some of the sights in downtown Darien include the Old Jail Art Center & Museum, which displays the work of local artists. Darien River Wine and Eco Cruises give visitors a unique opportunity to see historic downtown Darien, the shrimp boat fleet, and the unspoiled marsh and river system from the water. Wines are chosen from Waterfront Wine & Gourmet, and visitors learn about the natural and social history of Darien.

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<sup>20</sup> Interview with Altamaha Coastal Tours. September 28, 2013.

Darien is also home to a fair amount of restaurant activity such as the Waterfront Wine and Gourmet, a popular wine bar in Darien's historic downtown. Other restaurants in Darien include the Purple Pickle, Skipper's Fish Camp, B & J's Steaks and Seafood, Darien River House Restaurant, and Nautica Joe's Café. Lodging in Darien includes Open Gates Bed and Breakfast, Waterfront Inn, and Fort King George Motel.

Sea level rise will have lasting implications for many of the businesses in Darien, especially those who are directly located on the waterfront or are related to ocean activities. Small businesses are often ill-equipped to deal with severe weather incidents, such as flooding. Businesses such as hotels, bars, and restaurants often have no way of continuing their business in the event of a flood. Yet, studies have shown that the majority of small business owners have been under-insured (Clemo, 2008). The outsourcing of storage and distribution makes businesses even more vulnerable if transportation or other lines of infrastructure were damaged during severe weather or flooding (Clemo 2008). Small businesses are at great risk for being put out of business entirely in the event of a major flood or other severe weather incident. Increased incidence of flooding due to SLR and the recent changes to the National Flood Insurance Programs (NFIP) could have devastating effects on the small business community in Darien.

Preserving attractions like Fort King George, the historic downtown, and the Coastal Heritage Trail from Sea Level Rise is critical for Darien and McIntosh County. Much of the projected SLR is expected to inundate wetlands surrounding Darien. If the presence of developed areas prevents the wetlands from migrating inland as they would with their natural process, these habitats could be jeopardized. Historic places like Fort King George, Butler Island Plantation and the tabby ruins along the waterfront in Downtown Darien, are also at risk from SLR. To better understand the impacts to specific areas and tourism related businesses, we created the following maps found below.

- Figure 41 displays a number of small businesses in Darien, mainly around the downtown area. The layer of blue is the projected area of direct inundation for the year 2100.
- Figure 42 shows the projected inundation around Fort King George.
- Figure 43 shows the projected inundation around the Butler Island Plantation.

These historic places are located so close to marshlands that they are severely at risk for flood damage and inundation over the next 100 years.







**Figure 42: Inundation Projected around Fort King George due to 1 Meter Sea Level Rise**



**Figure 43: Inundation Projected around the Butler Island Planation due to 1 Meter Sea Level Rise**

### **Tourism, Small Business, & SLR: Implications of Research**

Darien is highly dependent on a few economic sectors, all of which are tied in some way to the ocean. Much of the tourism revolves around boat tours, kayaking, and other forms of ocean eco-tourism, and the small businesses often are dependent upon shrimping and seafood. Businesses owners should be educated on possible effects of SLR. Modeling indicates that the immediate impacts to the physical property in the town should be limited. Darien is located on bluff 30 feet above sea level, meaning the land on which many of these businesses sit will not be directly affected by sea level rise. However, eco-tourism could be significantly affected by alterations in the habitat, as could patterns of shrimp, crab, and other wildlife migration and spawning. The labyrinth of connections linking the well-being of the sea to the well-being of the economy should not be underestimated. For example, if a fishery fails, restaurants suffer, causing the revenue of lodging dependent on food tourism to decrease. As with any economy, there are significant interactions with the environment.



## RESIDENTIAL REAL ESTATE

According to the results of the previous studio, 30% of the residential areas in Darien are projected to be affected by SLR. The HAZUS results predicted that there will be 75 residential buildings affected by inundation. The total replacement costs for these buildings would be \$101,599 and the inundated building value would be \$10,003 (Keating & Habeeb 2012).

Coastal property is typically valued from 8% to 45% more than comparable inland property (Bin et al. 2011). A previous study by West et al. considered that SLR erodes protective coastal features which may increase the vulnerability of coastal communities to storm damage (2001). This is especially pertinent to Darien as adjacent wetlands serve as a protective barrier against hurricane and other forms in storm damage for the area.

A majority of the current literature, including the previous Georgia Tech studio report, calculate the impacts of SLR based on areas of permanent inundation. Another equally significant economic impact of rising sea levels, however, will be increasing incidence of flooding. In his article, "Measuring the Impact of Sea-Level Rise on Coastal Real Estate: A Hedonic Property Model Approach", Bin et al. found that the costs associated with storm flood damage are much higher than inundation. As a result, previous studies may have underestimated the costs of SLR in the US. In 1736, James Oglethorpe chose the location for Darien because it sits on a bluff, offering more protection for the city. This continues to give Darien additional defense from rising waters than many other coastal cities, but flooding will likely still present an issue that Darien residents and business owners will have to face.

Historically, homeowners' insurance has not covered damages to structures due to flooding. Property owners who experienced severe flooding were often left financially unable to recover after a flood. The National Flood Insurance Program (NFIP) was created in 1968 in part to provide relief to homeowners after flooding, but also to encourage new building practices and construction standards to reduce the risk of future flood damage to properties (FEMA). The cost of flood insurance was subsidized for existing homeowners to increase accessibility to insurance coverage. Flood insurance policies are provided through private insurance agents, but they are backed by the federal government.

Currently, the National Flood Insurance Program is undergoing massive legislative changes. With the Biggert Waters Flood Insurance Reform Act of 2012, the federal government is phasing out subsidized policy rates, which accounts for about 20% of all flood insurance policies (FEMA). On October 1, 2013, policy rate changes went into effect for non-primary/secondary residences, business properties in a Special Flood Hazard Area, and properties that have experienced severe or repeated flooding. Owners in each of these groups will see a 25% increase annually until their paid rates reflect the true risk of insuring their properties (FEMA). Property owners who hold flood insurance at their primary residence will keep their current rates until they sell the



property, have a lapse in the policy, experience severe, repeated, flood losses, or purchase a new policy.

Of the 1,090 total housing units in Darien, 82 or 7.5% are seasonal homes (2010 Census). The number of these seasonal homes within the flood plain is uncertain. Increasing flood insurance costs will likely have a negative impact on the seasonal housing market, which composes a small, but important portion of Darien's housing stock. Increased housing vacancy can also put an increased strain on Darien's local economy.

There are some ways to reduce flood insurance costs. The Federal Emergency Management Agency suggests that homeowners talk to their insurance agent about insurance options available to them. Property owners should obtain an Elevation Certificate to determine the correct rate for their property. Further, taking on an increased deductible could lower premiums. Homeowners or business owners should consider incorporating flood mitigation into remodeling or rebuilding of homes or building as well as consider adding vents or using breakaway walls (FEMA).

## COMMUTE PATTERNS

Even when homes in an area are untouched by rising waters, the places where these residents work can be affected. The effects of SLR are widespread; as such, this section will analyze the commuting patterns of Darien residents as a way to measure the overall impact of SLR on the residents and the economy of Darien, and not just the physical damage inside the city limits of Darien itself.

In performing this analysis, commuting data and patterns were acquired from the U.S. Census Bureau's online commuting pattern application, *On the Map*. Using *On the Map* data, the analysis was conducted at the county, city and detailed location level. This data was then imported into ArcGIS 10.1 to explore spatial patterns and the impact on commuters from the SLR projections.

Figure 44a below shows the commute destinations by city of Darien residents. The top 10 destinations are highlighted, with each city having at least 9 workers commuting to it. The cities with the highest worker totals are Brunswick (with 76 workers), Savannah (67), Darien (30), St. Simons (22) and Dock Junction (22). These cities account for 269 of the 511 commuters that live in Darien. Visual representation of these cities can be seen in Table 29 below. Figure 44b shows the same commute data on a county level, following the same parameters as Figure 44a. Intuitively, Chatham and Glynn counties are the most affected, as they include the most affected cities.

**Table 29: Top Darien Commuter Destinations**

Work Destination	Number of Workers
Brunswick	76
Savannah	67
Darien	30
St. Simons	22
Dock Junction	22

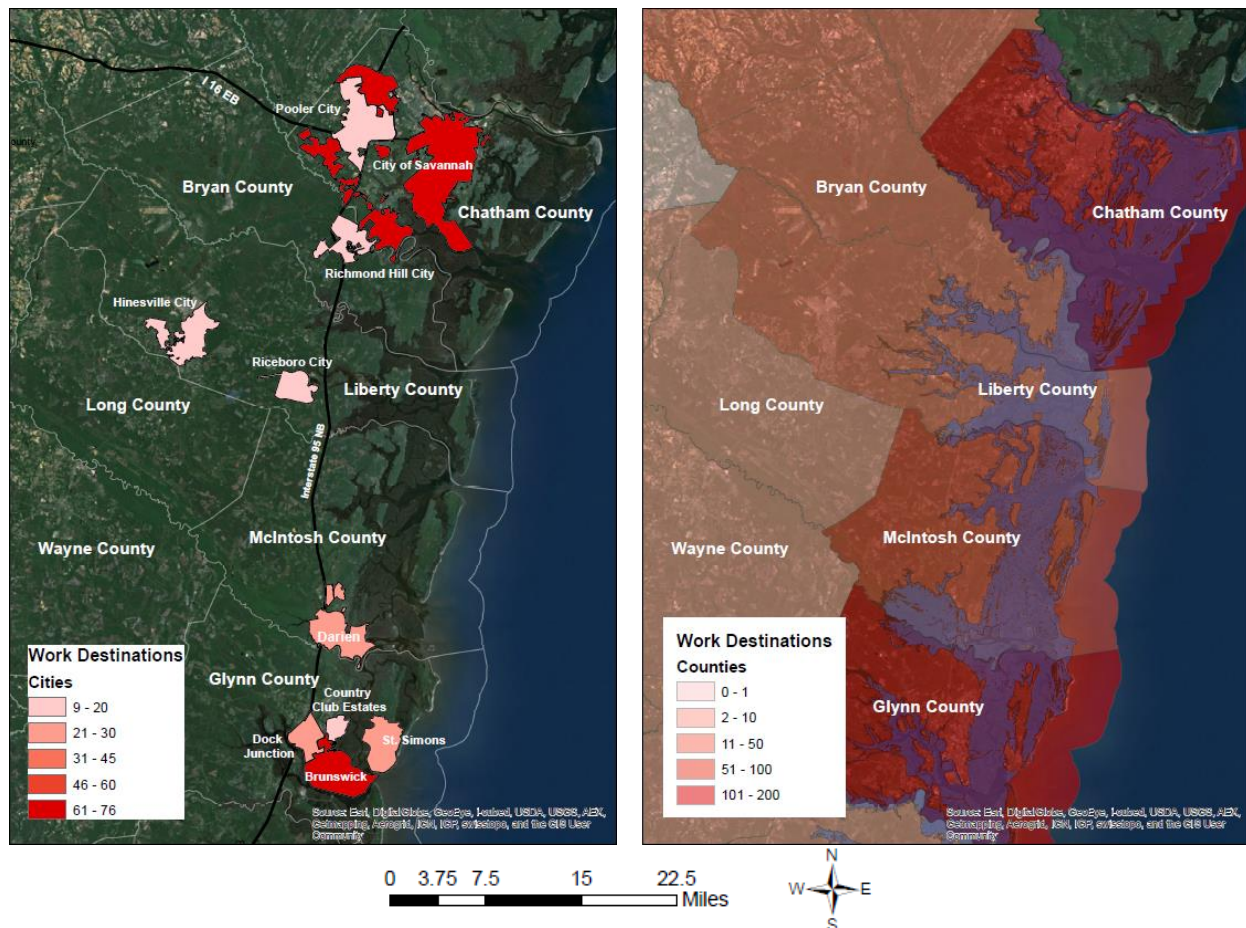
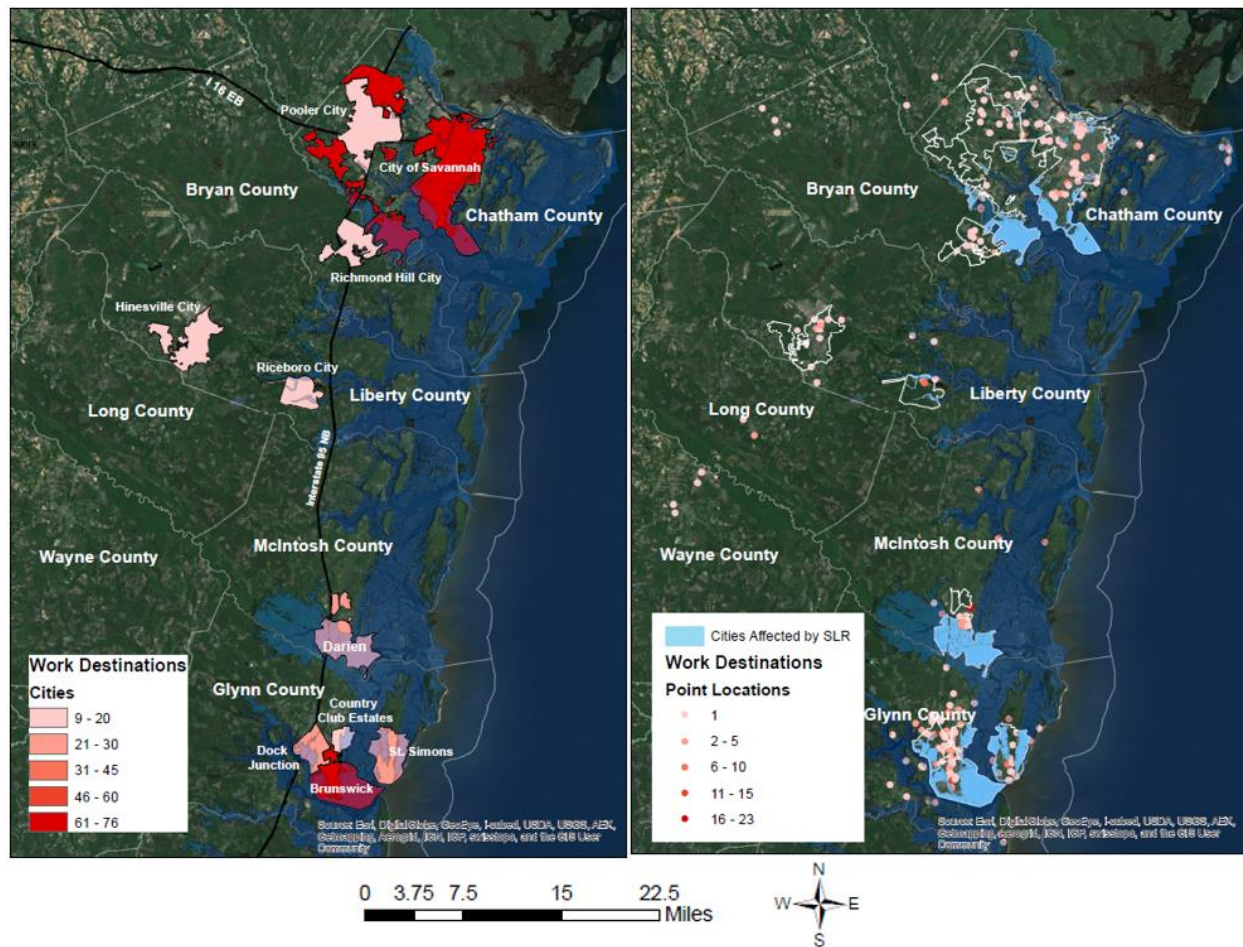


Figure 45a overlays the projected 1 meter SLR with the city commute data. In each of these cases, the SLR projection gives a visual of how much of the city land is inundated but not how many jobs are lost, as much of this land is marsh land. In Figure 45b, the employment data is broken down into smaller points, with each point representing 1-23 jobs. This map gives provides a clearer understanding of how many jobs are affected by SLR. Figure 45b further shows the city limits in a white outline; portions affected by SLR are colored in light blue.



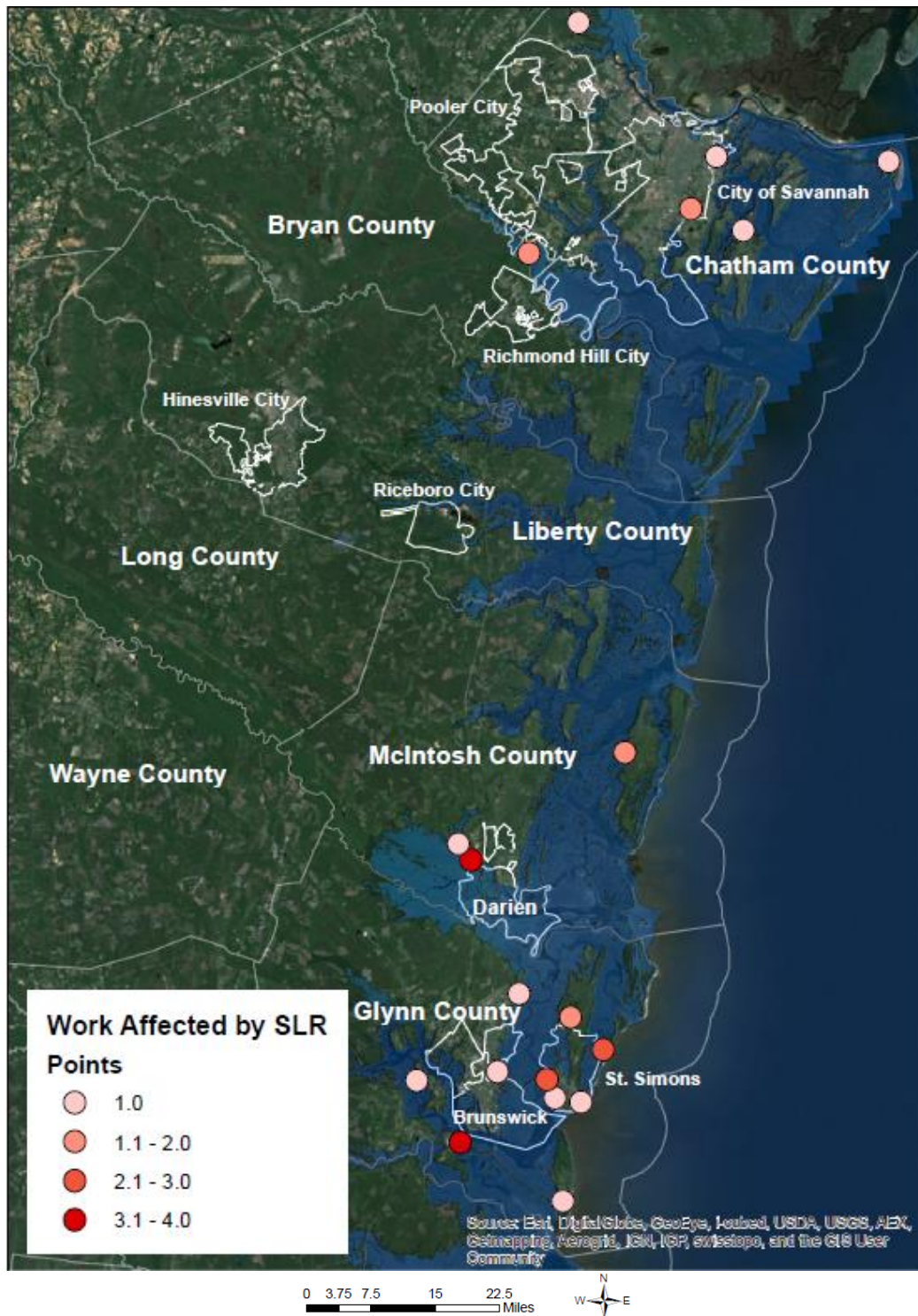
(a) By City

(b) By County

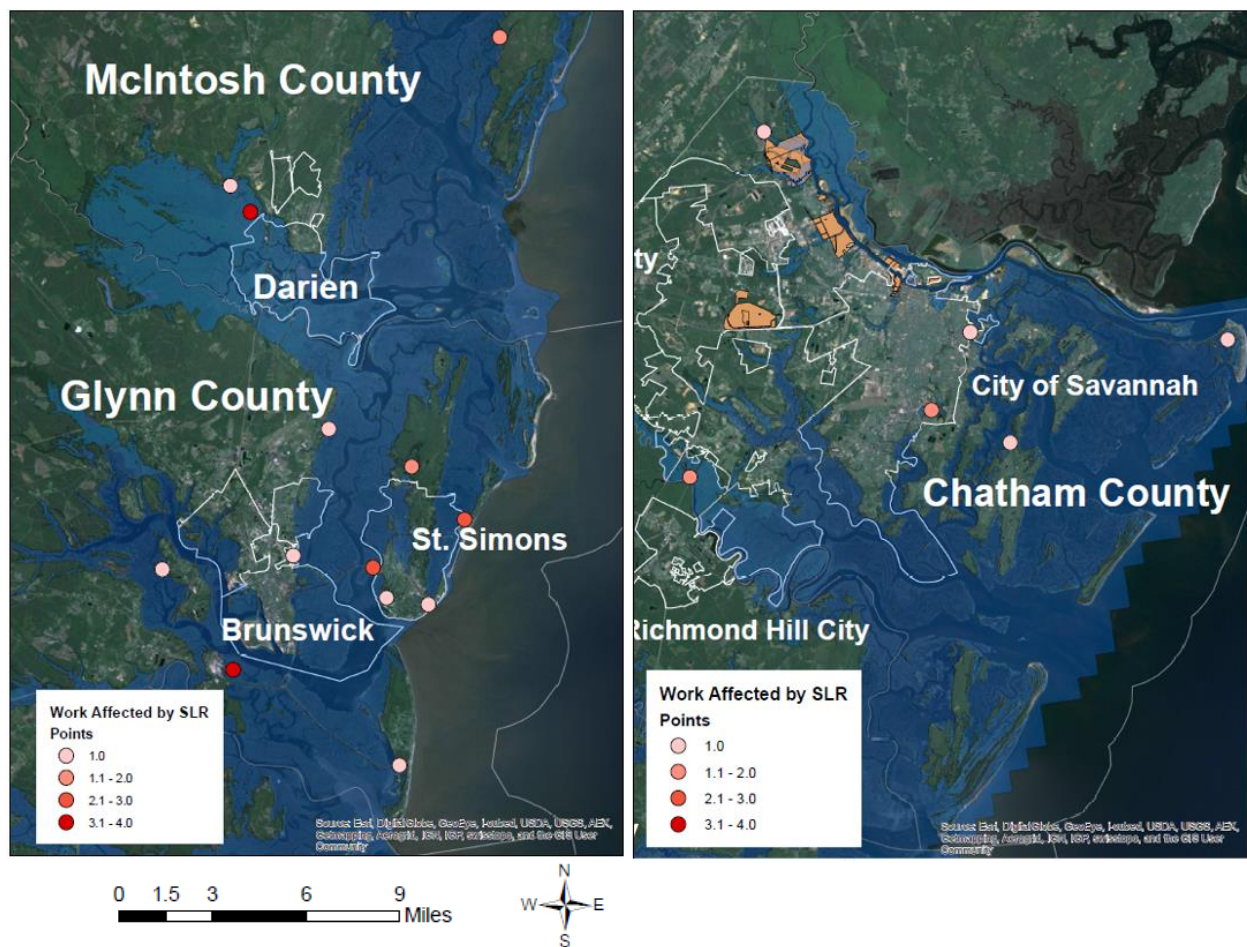
**Figure 45: Darien Work Destinations**

Finally Figure 46 shows only the work points, representing 1-4 jobs each that will be affected by SLR. Figure 47a and Figure 47b show this same data at a finer scale for the southern and northern portions of the area of analysis.





**Figure 46: Affected Darien Work Destinations by Points**



(a) South

(b) North

Figure 47: Affected Darien Work Destinations

## Implications

From the data presented above, it can be seen that very few points fall inside areas that will be affected by SLR. Points, instead, tend to cluster around those areas of cities that will be least affected by SLR. Map 6 demonstrates that there are no affected Darien residents working on Georgia Port Authority property in Chatham County, which is shown as brown polygons. Out of all of the workers living in Darien, only 33 workers commute to a place that will be inundated by SLR under the 1 meter projection.

In absolute terms, 33 workers is a very small number, however, it represent 6.5% of the entire working force of Darien. Further this analysis indicates that the vast majority of working adults are leaving the city of Darien to work. This means that the economy of Darien is highly dependent on neighboring cities and communities, and if this trend continues, work centers may shift eventually shift to places more affected by SLR.

Several limiting features of this analysis deserve further consideration. The commuter analysis might not fully take into account all of the workers that live in Darien. For

example, the numbers do not appear to reflect all those workers working in the fishing industry. Workers could be left out because they are getting paid under the table or because the Census has had to suppress the data to protect the anonymity of a very small number of businesses. The methodology fails to account for the inundation of roadways that Darien workers might use across the coast to reach their destinations. An analysis of the major coastal roadways can be seen in the commuter section for the Port of Savannah analysis, found on page 44. Below is a table (Table 30) taken from that section, which shows the amount of roadway that would be damaged by SLR inundation (the majority of which would affect Darien commuters). Also, in that section can be found maps of the roadways and SLR as well as cost calculations for roadway repairs due to SLR.

**Table 30: Length of road network inundated under one meter of sea level rise (in miles)**

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	<b>Total</b>
Short Span (including shorter span bridges) (0'-45')	0.083	0.011	0.194	0.098	<b>0.386</b>
Medium/Long Span (45'+)	3.701	1.764	12.388	4.351	<b>22.204</b>
<b>Total</b>	<b>3.784</b>	<b>1.775</b>	<b>12.582</b>	<b>4.449</b>	<b>22.589</b>



## ADAPTATION STRATEGIES

Damage from natural disasters often occurs suddenly and without warning, giving communities little time to prepare and make accommodations. Conversely, SLR occurs gradually. Because this change occurs slowly, however, communities are often reluctant to act on this change, instead opting to focus investment on more immediate concerns. According to the 2007 IPCC report, an 8" rise in the ocean level occurred between 1961 and 2003. Global sea levels rose an average of 1.8 mm (.07 in) per year between 1961 and 2003 and at an average rate of about 3.1 mm (.1 in) per year from 1993 to 2003. This trend leaves our coastal communities vulnerable to damage from increased flooding and inundation.

While the exact extent to which sea levels will rise is difficult to predict and subject of debate, it is certain that they are rising. For this study, we have anticipated the effects of a 1 meter rise in sea level over a 100 year period. One hundred years is a very long period of time to plan for, but taking precautions now will reduce the physical, environmental, and economic impacts that may be experienced as a result of SLR. This is an opportunity for leaders along the Georgia coast to help their communities prepare for the coming change.

## ECONOMIC IMPACTS

The City of Darien has such a small economy that any amount of economic impact will be felt more acutely here. Their three key industries, commercial fishing, tourism and small businesses, and residential real estate, will all experience varying degrees of impact from SLR. According to the analysis performed by Keating and Habeeb, 29% of all land in Darien is projected to be inundated if sea level were to rise 1 meter by 2100 (2012). Much of this area is wetlands or recreational land, but the wetlands are a vital component of Darien's economic vitality.

The HAZUS model estimated that 75 residential buildings will be inundated in Darien, but 32.4% of Darien's industrial buildings and 7% of commercial buildings will be inundated as well (Keating & Habeeb 2012). Though these buildings will be directly impacted, nearly all businesses and residents could feel indirect impacts from SLR. If the businesses in the commercial and industrial buildings that are expected to experience inundation decide to relocate outside of Darien in an area that is safe from SLR, this could mean a loss of employment opportunities in an area that is particularly vulnerable due to its lack of business diversity.

## STRATEGIES

There are many strategies to help local communities adapt to rising sea levels. The three main traditional adaptation categories include *Armoring*, *Retreat*, and *Accommodation*. Each coastal area presents a unique environment with a different set of needs. It's important to choose the strategies that best fit the conditions of the community. Figure 48 below summarizes the three categories, their main strategies and pros & cons.



**Figure 48: Adaptation Strategies**

## RECOMMENDATIONS FROM A PLANNING PERSPECTIVE

Dwight Eisenhower, once said, “In preparing for battle I have always found that plans are useless, but planning is indispensable.” With so much information available about SLR, it can be daunting for communities to even know where to begin with their planning process. Good planning processes almost always begin with involvement from the community and formation of stakeholder groups. It is imperative to involve local stakeholders, including residents and business owners, in the planning process because they are often the groups most impacted. SLR could displace residents from their homes and could significantly affect local businesses.

Local governments will be responsible for implementing some of the strategies mentioned above, but property owners will decide on which actions they would like to take on an individual basis as well. Educating community members about the local risks of SLR must be a key component of the overall community strategy. Certain adaptation strategies, especially those associated with retreat, may be seen as politically unfavorable to the public when they are unaware of the risks associated with inundation (Taylor 2013). Including an educational component will help to encourage engagement and achieve local buy-in.

Cost is almost always the most important variable in deciding which adaptation strategies a community chooses. Local leaders must weigh the cost of adaptation strategies versus the cost of damage to property and economic loss incurred by SLR (Yohe 2011). Most studies lack specific damage assessment information, largely because the actual costs vary widely from place to place and modeling can be very complex (Kirshen 2012). Modeling so far into the future requires the expectation that costs will rise as the sea levels continue to rise. If the economy does not grow at the same rate as these costs, this could present a serious problem for local governments who are already lacking available resources and funding (Huntington 2012). A cost-benefit analysis would help local leaders determine how best to utilize their limited resources.

The case study the section below gives an example of a community planning process that utilized these approaches in deciding on their strategies for adapting to SLR.

## CASE STUDY

*The New Hampshire Coastal Towns of Seabrook, Hampton & Hampton Falls (Merrill 2012)*

In 2011, The New Hampshire Coastal Adaptation Workgroup (NHCAW) partnered with the New England Environmental Finance Center to develop a SLR adaptation plan for three towns on the coast of New Hampshire: Seabrook, Hampton, and Hampton Falls. The New England Environmental Finance Center developed a tool called COAST (Coastal Adaptation to Sea level rise Tool) to help communities with the SLR planning process by assessing the social, political, and economic realities of local adaptation measures. The goals of the COAST tool are to encourage communication, educate the

at-risk public about the estimated impacts, and help communities decide for themselves which strategies work best for their local area. This stakeholder-driven process encourages inclusivity and steers the direction of the overall strategy to reflect the values of the community.

In their first meeting, stakeholders were introduced to the COAST modeling process, discussed the areas that were most vulnerable to SLR, evaluated the public opinion of SLR risks, and selected the vulnerable assets in the community that they wanted to assess in their model. The stakeholders at this meeting chose to focus on the impacts to real estate. At the second stakeholder meeting, results from the model were presented to the group. These models allowed the participants to see the potential impacts on their local and familiar places. After comparing these models, stakeholders identified areas of concerns that included vulnerability of important highways, preservation of evacuation routes, important facilities, and preservation of beaches. They then chose three adaptation strategies: preservation, protection, and accommodation.

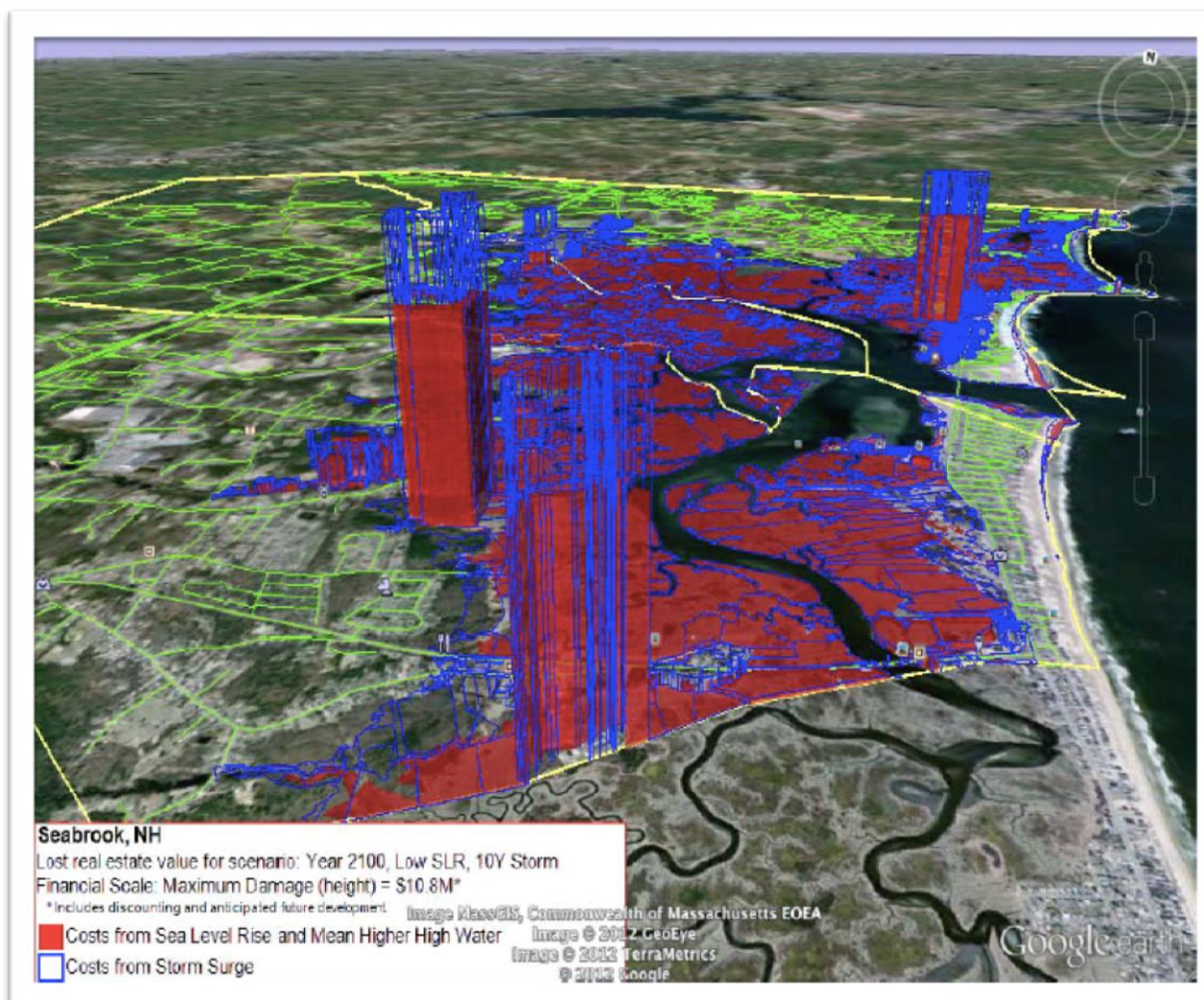
They elected to maintain natural buffer capacities and estuary habitats by ensuring that tidal flow is not restricted by marsh and road crossings. They determined that physical barriers should be used to protect vulnerable real estate. They also recommended that homes and businesses that are vulnerable to flooding should be elevated or flood-proofed. They then determined that cost/benefit analyses should be conducted for the actions to protect real estate.

In later meetings, the team discussed challenges, barriers and opportunities revealed by the model results. They outlined actions that should be taken by community leaders. Overall, the group determined that the strategies for adaptation varied by location and type, but the benefits of accommodation actions consistently outweighed the costs. Other communities may benefit from key take-away points identified in discussions:

- Three-dimensional maps are very useful communication tools. (An example is found in Figure 49)
- It is important to frame adaptation as a relevant issue for today, and keep a positive tone.
- Individual, self-generated solutions will be the most robust – solutions must come from communities themselves.
- Groups should focus more on application of results than on the technical process (let the extension/university/agency/consulting assistants focus on technical elements).
- Future collaborations for adaptation should be regional and multi-jurisdictional

Overall, the strategies decided on using the COAST tool and stakeholder meetings helped three cities to utilize technical information in order to facilitate communication within their community to make their region more resilient in the face of rising sea levels.





**Figure 49: Lost Real Estate Value for the Year 2100, Low SLR, 10-year Storm in Seabrook, Hampton, and Hampton Falls, NH**

## COMMERCIAL FISHING

Adaptation strategies to sea level rise for the commercial fishing industry can best be organized into short and long term strategies. Because the future of this industry is already uncertain, it will be necessary to take actions in the near future to ensure commercial fishing's continued viability along the Georgia coast. With shrimpers threatened by rising fuel costs and stiff competition from imported seafood from Asian and South American farms, expanding the Georgia Shrimp Association's "Wild Georgia Shrimp" marketing campaign to educate consumers on the merits of wild-caught Atlantic shrimp and blue crab as compared with pond-raised imports will be an important if the industry is to compete. Though Georgia caught seafood offer the freshest catch available to most Georgians, the greater costs associated with harvesting these wild Atlantic shrimp and Georgia-caught blue crab have lead may restaurants, including many along the coast, to offer the less expensive pond-raised alternative. These restaurants often pick domestically caught seafood when the price disparity between domestic and imported shrimp is small, but conversation with a Macintosh County-based seafood distributor indicated that they become increasingly less willing to do so when the premium for locally caught seafood nears \$0.50 per pound<sup>21</sup>. By helping to create a better awareness among consumers, Georgia restaurants will be more likely to pay a higher premium for the local product.

Flexibility to move between fisheries will also be essential for the commercial fishing industry to survive. Some fisherman have already begun to recognize the importance of flexibility and are diversifying their catch into shad from January to March and snapper and grouper when the fisheries are healthy and can be sustainably fished, allowing the trip limits are raised. The current difficulty with creating this flexibility, however, is large barriers to entry. Commercial fishing permits for some fisheries can be prohibitively expensive. In order to fish for snapper or grouper, for example, a fisherman must acquire two South Atlantic Snapper-Grouper permits and retire one, at a total cost of between \$35,000 and \$40,000. Permits for many other fisheries also often sell for between \$5,000 and \$10,000<sup>22</sup>. Further, many of these alternative fisheries have, themselves, experienced overfishing. The necessary equipment to move from one fishery to another can also contribute to the large financial costs of flexibility. While large freezer shrimping vessels can transition easily from one inshore species to another, it requires a significant investment in new equipment to transition to offshore species. Other fishermen have begun to explore species with fewer regulations, such as the introduction of the cannonball jellyfish fishery in the 1990s. Due to the limited processing facilities, the very low cost per pound, and potential for overfishing as has occurred in some Asian markets, there is reluctance on the part of many fishermen to enter this fishery. A key, then, may be to explore additional new and innovative fisheries. One fisherman we spoke to, for example, was investigating the potential of three species of shellfish on which no aquaculture was currently being conducted.

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<sup>21</sup> Interview with local fisherman by John Risher and Andy Cornwell. Darien, GA. October 18, 2013.

<sup>22</sup> Ibid.

Ultimately, even with such innovation, it may be necessary for many of these fishermen to transition to new industries.

From a longer-term perspective, however, estuarine environments and wetlands around the Darien coast are essential for providing healthy fishery populations. Currently, existing wetlands are protected through both federal and state regulations, including Georgia's Coastal Marshlands Protection Act, Shore Protection Act, 401 Water Quality Certification, and the Water Quality Control Act (Water Quality in Georgia 2006-2007 2008). The state has also engaged in a land acquisition strategy, in combination with public education programs that has protected more than 200,000 acres through Preservation 2000 and RiverCare 2000 acquisition initiatives and program expansions (Water Quality in Georgia 2006-2007 2008). As demonstrated through the SLAMM model, however, these wetlands will not remain static over the next century. Land use controls need to account for not only existing wetlands, but also adjacent parcels, which may face future inundation and wetland migration. In order to protect these vital habitats and nursery grounds communities should examine in greater depth the impacts of wetland migration.

Local governments along the Georgia coast, including the town of Darien and McIntosh County, could best prepare for rising sea levels by tying their land use decisions not to static assumptions about the land cover make up across time, but under a dynamic model of wetland creep. The SLAMM model utilized in this report examined 30 meter by 30 meter cells across a wide geography calculated through SLAMM model version 5.0.1. In 2010, Warren Pinnacle Consulting, through funding provided by the Nature Conservancy, updated and released a Beta version 6.0, which includes dynamic accretion, an updated salinity component, elevation analyses, and increased flexibility in parameterization (Clough 2010). By partnering with experts on wetland habitat and sea level rise, such as the Skidaway Institute of Oceanography, and running the updated model at the finer grain 5 meter by 5 meter cell size, local governments would provide themselves with a valuable tool in setting land use controls that protect not only existing wetlands, but by preventing development in future wetland sites, which could prevent migration of the valuable wetland habitat.





**Figure 50: Darien Wetlands**

## TOURISM AND SMALL BUSINESS

Tourism sites in Darien face significant danger from sea level rise. The most important sites, Fort King George and the Butler Island Rice Plantation, are both located in inundation zones where they will likely suffer severe damage from sea level rise over the next 100 years. Drastic changes in the surrounding environment will impact how visitors experience these sites as the histories of both Fort King George and the Butler Plantation are closely intertwined with their surroundings. Additionally, wetlands and other natural areas are likely to be affected by sea level rise within Darien, which will impact ecotourism in the area. Fauna and flora in the area that provide sources of tourist attraction should be evaluated closely to determine any impacts of sea level rise on them. The uniqueness of these tourism-related concerns suggests that besides the traditional methods of sea level rise protection like accommodation, armoring and retreat, directors of tourist attractions in Darien should consider other methods to protect their sites from sea level rise and to educate the public on its effects.

It would be prudent to determine to what extent the three traditional methods can help protect the coastal tourist areas. The Fort King George consists of several structures, including replicas of pre-Revolutionary blockhouses, enlisted soldiers' barracks, guardhouse, and officers' quarters. The Butler Island Rice Plantation consists of a residence, a 75-foot brick chimney that used to be power of rice mill, and a dike system. The possibility of protecting these structures through armoring (whether hard or soft restructuring) should be investigated by the directors of the site. Retreat may initially seem implausible, but reconstructing these buildings further inland may be a requirement to protect these historical treasures. Accommodation mostly refers to future development, and is not particularly relevant to protecting these historical sites.

Another appropriate measure to help protect these historical sites would be education about the effects of sea level rise. Education is already an important part of historical site visitation; educational lectures and material distributed at these sites should also place emphasis on how people can limit their impacts on these environments. Employees of these historical attractions could also educate visitors about the surrounding environment, and how human interaction with the environment can potentially exacerbate issues related to sea level rise.

Teaching visitors about their personal impacts on sea level rise is even more important in the ecotourism sector. While many eco-tourists may already be more educated than the average traveler regarding the impacts of sea level rise, seeing the impacts of sea level rise up close and personally in the Georgia marshlands (which make approximately one-third of the all marshlands found on the east coast), and seeing the unique beauty of the wildlife may encourage them to better appreciate the consequences of sea level rise.



**Figure 51: Fort King George in Darien**

Source: [http://upload.wikimedia.org/wikipedia/commons/0/0f/GA\\_Darien\\_Fort\\_King\\_George09.jpg](http://upload.wikimedia.org/wikipedia/commons/0/0f/GA_Darien_Fort_King_George09.jpg)

Business activity in Darien might also be heavily impacted by sea level rise. In addition to the impact of sea level rise on commercial fishing, sea level rise poses a significant threat to other industries located in Darien like lodging, real estate, and restaurants. Though very few physical structures occupied by small businesses will be directly affected by sea level rise, their operators may be affected by impacts on different industries or different geographic regions. For example, lodging is an important industry in Darien. Ten hotels/lodging facilities exist in the town. Many visitors to eco-tourist sites in the surrounding county, including nearby Sapelo Island, depend on lodging in Darien for their visitations. Business plans for the coming years should take into account possible declines in business as sea level rise begins to have substantive effects on activities beyond Darien's city limits.

Businesses that are in the direct path of future inundation from sea level rise, such as the Super 8 on I-95 at exit 45, will need to relocate further inland if the hotel is to remain open. Other businesses that are sensitive to changes in the soil and beach, like the Altamaha Coastal Tours, may also be forced to relocate.

Other measures focus on mitigation rather than simply adaptation, including converting building structures into “green” facilities, should also be considered. This means constructing buildings that efficiently use water, energy, and other resources and reduce waste, pollution, and environmental degradation. While these goals do not have immediate impacts on small business’s battle against sea level rise, they do provide long term benefits that will help stem the tide of increasing in sea levels.

## Summary of Findings

The studio's analysis of the Port of Savannah's Garden City Terminal and the City of Darien have revealed many important economic impacts of sea level rise in both, very diverse locations. Key findings at the Port of Savannah include the following:

- Sea level rise is unlikely to permanently inundate significant amounts of the Garden City Terminal or nearby warehouses. The storm water drainage canal that bisects the Garden City Terminal and lowlands near the Mason Intermodal Container Transfer Facility may incur limited flooding due to one meter of sea level rise, but infrastructure improvements are likely to mitigate most effects. Similarly, fewer than 2% of Chatham County's warehouse acres are likely to be permanently inundated.
- Sea level rise and storm surge may threaten a limited number of homes of employees at the Garden City Terminal. The Georgia Ports Authority has detailed employee residence information that may illustrate potential future impacts of sea level rise on the port labor force.
- Sea level rise is like to require expensive retrofits of coastal roads, many of which transport port-related trucks. The exact cost of retrofit depends on water heights, engineering methods chosen, material costs, and many other variables. The study team estimates that adaptation for regionally important roads in Georgia's coastal counties may range from \$349 million to \$922 million. 84 private rail segments may also be inundated.
- Sea level rise may increase storm-induced flooding at the Garden City Terminal, resulting in port closures, which would reverberate through the local and state economies. A category one hurricane may result in \$1 billion of reduced output through the Garden City Terminal and a \$537 million harm to the state GDP. For a category 3 storm, output reduction is over \$1.5 billion and GDP reduction is nearly \$752 million. A category 5 storm could close the Garden City Terminal for weeks, resulting in \$13.5 billion in lost output and \$6.6 billion harm to the state GDP.
- While hurricanes have been rare in recent years, the historical record suggests that hurricane strikes on Georgia's coast are likely in the medium term, and sea level rise is likely to worsen the resulting flooding. Sea level rise will make all storm categories affect more properties in Chatham County and worsen flooding. Sea level rise is also likely to worsen surge-related flooding at the Garden City Terminal, making even minor hurricanes flood much of the terminal by several feet. Finally, sea level rise increases the vulnerability of warehouses near the Garden City Terminal to storm surge, both in terms of the extent and depth of potential flooding.

- Finally, sea level rise may negatively impact the Garden City Terminal by increasing river salinity and concomitant infrastructure corrosion and decreasing vertical clearance for ships entering the port.

The studio's analysis also unveiled important sea level impacts at the City of Darien. As a town whose primary industries are fishing and tourism, the sea level rise impacts are of a different nature than the infrastructure- and logistics-based impacts at the Garden City Terminal.

- Sea level rise is likely to change the salinity levels in fish and ocean invertebrate habitats, further degrading the species there. Commercial fishers and shrimpers in Darien are likely to bear the brunt of any harmful effects to local fishing communities. Fishers will need flexibility to move along the coast and diversify their dependence on fisheries to help the industry survive. Efforts to protect the estuarine environments and wetlands will be important to sustain the fishing industry.
- Land use controls need to account for not only existing wetlands, but also adjacent parcels, which may face future inundation and wetland migration. In order to protect these vital habitats and nursery grounds communities should examine in greater depth the impacts of wetland migration.
- Tourism may suffer if sea level rise degrades wetlands and other natural attractions around Darien, and other historic sites—including Fort King George and the Butler Island Rice Plantation—will likely ultimately suffer permanent inundation. It will be important to the local economy to protect historic and natural tourist attractions as much as possible through protection or relocation. Tourism may also present opportunities for public outreach on sea level rise through education about the effects as manifested in Darien.
- Many small businesses in Darien may be indirectly affected by sea level rise, including hotels, restaurants, and tour companies whose customers come for historic or eco-tourism. Some businesses may be faced with long term prospects of relocation, or a disruption of materials used for their business such as local fish.
- The residential real estate industry will be impacted by a greater chance of storm surge flooding, and an increase in rates for flood insurance. This may make owning a home overly expensive for some seasonal or permanent homeowners.



## Conclusion

As we have seen in Darien and the Port of Savannah, sea level rise confronts industries and communities with very real challenges to livelihood, heritage, the environment, and physical and economic wellbeing. These challenges exist not only at the Port of Savannah and in the City of Darien, but also in numerous other coastal communities. The impacts are not purely local, however. Regional, national, and even international economies tie working waterfronts to businesses and communities hundreds of miles away so that impacts from coastal sea level rise impacts propagate outwards through economic interactions.

This report has analyzed many of the connections that exist between working waterfronts of different sizes and the broader economy. Though the Port of Savannah and City of Darien are very different from each other in size, industry make-up, and level of industrialization, it is unequivocal that the communities are linked with broader economies that sea level rise threatens to disrupt in multiple ways. The analysis provides several overall findings that may guide efforts by the business community, policy makers, planners, stakeholders, and citizens in sea level rise preparations.

### Sea level rise effects exist at many different scales

Sea level rise is not purely a local issue, though—to be sure—there are local effects. Sea level rise threatens localized inundation, increases storm-related flooding, environmental changes, and disruptions to small and large businesses alike. However, economic connections cause local effects to spill over into regional economies. Employees at disrupted businesses carry sea level rise impacts back to their homes in lost wages. Disrupted freight flows may disrupt warehouse operations in other counties that process port shipments, decreased catches may affect fish, shrimp, or jellyfish processing or tourism, and permanent or storm-related flooding may harm regional road and rail infrastructure.

Disrupted coastal activities may also threaten economic activity and industry clusters elsewhere in the state that depend on coastal ports and industries. The Port of Savannah is one of the largest and fastest growing container ports in the country, which means that its flows impact Georgia and other states far beyond Georgia's boundary.

Finally, economic processes reveal how global effects of sea level rise and climate change are linked at the national, state, and local levels. Melting Arctic waterways may open new trade routes and change trading partners, just as changing ocean environments could in the long term change fish habitats or migratory patterns. Both effects are unpredictable. They may occur thousands of miles from the Port of Savannah or Darien yet still impact demand for each location's exports and services. Economic analysis is important because it uncovers connections at numerous different scales in sea level rise impacts that other analysis does not address. Economic impacts are among sea level rise's most important and least studied impacts.

## Continuing research on sea level rise should also seek to understand sea level rise's economic impacts

The research report has analyzed two very different locations on the Georgia coast from an economic perspective. It uncovered important relationships and impacts that can help communities to prepare for sea level rise. Future research should build off of the relationships documented in this research report by addressing economic impacts in new locations, uncovering nuanced applications, or assessing economically viable responses to protect against sea level rise. The research has the potential to improve the ability to recommend appropriate mitigation efforts that are justified by economic impacts, meaning that it would be easier for leaders to justify corporate, individual, or tax dollar investment into mitigation efforts. As is apparent in Darien, armoring, retreat, and accommodation may each be appropriate in different circumstances. The choice of appropriate strategy depends on other demographic, social, cultural, and historical factors, but economic impacts are particularly important because of the connections at different scales and the fiscal constraints within which communities exist. Economic analysis allows decision maker to prioritize mitigation efforts to those areas with the largest and most widespread impacts.

## Planning for sea level rise when infrastructure is built or rebuilt allows engineers to build in protections at little or no additional cost

This study addressed sea level rise affects over a one hundred year timeline. Sea level rise and concomitant effects will be progressive, meaning that the timeline for sea level rise will surpass the useful life of many pieces of infrastructure, including wharves, roads, and bridges. Moreover, research has revealed that most ports operate on a five-to-ten year planning horizon even though much infrastructure's useful life is beyond ten years. If infrastructure is not built to account for sea level at the end of its useful life, sea level rise may disrupt operations or require more expensive retrofit during the useful life. It is also important to note that sea level rise is not expected to stop one hundred years in the future or at any particular date, even though this study used a one-hundred year timeframe to ground analysis. Thus, infrastructure managers will need to remain abreast of sea level rise models in case the amount or timelines change. The models do not currently make clear the height or level of protection that will allow infrastructure to be safe in perpetuity. Instead, there will be needs to address sea level rise in infrastructure construction and reconstruction as sea levels change.

## Stakeholder outreach is needed to begin addressing sea level rise impacts

Economic analysis offers a possibility to change the conversation that exists in public outreach, revealing linkages between coastal and inland communities in a way that highlights invisible stakeholders in sea level rise adaptation and mitigation efforts. Sea level rise has many stakeholders, and not just on the coast. They may include coastal residents and business owners, county and municipal leaders, coastal investors, logistics companies, port users, port employees, freight companies, fishers, shrimpers, and exporters, and many others linked economically with areas likely to suffer sea level rise effects. Strengthening public outreach will enable them to take the actions that they can to prepare and protect their long-term interests while also kick starting the public discourse that must exist to support democratic decision making. Addressing sea level

rise will require both public and private actions; stakeholder outreach is a starting point for each.

Sea level rise will challenge working waterfronts in new and unprecedented ways. This report has shown how sea level rise may affect the Port of Savannah and the City of Darien, and how those impacts may propagate at the local, regional, and state scale. Building future sea level rise analysis based on economic impacts can lead to economically justified, fiscally constrained, culturally sensitive, and environmentally necessary mitigation steps to help protect working waterfronts and inland communities.

## Appendix 1: Bathtub Model

The “bathtub model” is normally used to approximate sea level rise based on the assumption of uniform water level rise at all levels of the land being examined. The bathtub model is useful to project uniform sea level rise by assuming inundation on all land below a specified elevation. It can in some cases also model storm surge, but the results are less accurate than for sea level rise because the assumption of equal water levels does not hold for storm surge. In storm surge, water levels are affected by wind direction, air pressure, seafloor and land contours, and natural obstacles.

## Appendix 2: Road Network Reconstruction Cost Methodology

The study team assumed that each segment of major road inundated under one meter of sea level rise would be raised as a bridge. Therefore, in order to quantify the adaptation costs for the road network, the study team estimated a range of costs for each of the inundated segments.

The study team used roadway shapefiles for the six coastal counties that were obtained from the U.S. Census Bureau. For four of the counties, the functional classifications were already coded into the shapefile. The study team then used GDOT's functional classification maps to code the functional classifications of the roadways in the remaining two counties, and merged the six county road networks into one regional road network layer. Once coded and merged, the study team selected only the four most important functional classifications for mobility (interstates, freeways/expressways, principal arterials, and minor arterials) and created separate layers for each of these functional classifications. The study team then intersected the inundation map created in the previous studio with the layers for each of the functional classifications to identify the segments in each functional classification that would be inundated. Next, for each functional classification the study team calculated the lengths of each of the segments, and exported the results to an Excel file, where the team completed the remainder of the calculations.

At this point, the study team had four tables. All contained a list of roadway segments inundated along with the corresponding lengths of the segments that would be inundated. The tables were divided by functional classifications; one contained the interstate segments, another freeway/expressway segments, and so on. The study team then calculated the range of the typical minimum cross section widths for each of the functional classifications. It is important to note that the inundated segments were grouped by functional classification since the characteristics that go into the calculation of a typical minimum cross section width, such as average number of lanes, minimum lane width, and minimum shoulder width, vary for the different functional classifications. The team calculated these ranges for each of the functional classifications by multiplying the range of minimum lane widths by the average number of lanes and adding the range of minimum shoulder widths. The values for each of these variables, average number of lanes, range of minimum lane width, and range of minimum shoulder width, were obtained from the Federal Highway Administration.

Next, using the tables with the list of segments and corresponding lengths and the range of minimum cross section widths, the study team calculated the range of minimum bridge area for each of the segments. The study team simply multiplied the range of minimum width by the length to determine the range of minimum bridge area. Finally, the study team applied the appropriate range of per square foot bridge construction cost estimates published by the Florida Department of Transportation (FDOT). FDOT classified bridges as short span or medium/long span bridges which had different ranges of per square foot construction costs. The study team used if/then logic in Excel to apply short span per square foot bridge costs to short segments (< 45') and

medium/long span per square foot costs to short span bridges. The study team multiplied the range of minimum bridge area (in square feet) by the appropriate range of per square foot bridge construction costs to obtain the range of construction costs for each of the segments. The study team then aggregated these values to obtain the impacts along the entire Georgia coast.



### Appendix 3: Methodology of the UGA Deepwater Ports Study

The study team primarily used economic inputs provided by the University of Georgia's 2012 report, "Economic Impact of Georgia's Deepwater Ports," to quantify the economic impact of a one meter of rise in sea level at the Garden City Terminal ("UGA Study"). The UGA study looked at the economic impact of the Port of Savannah and Port of Brunswick (Georgia's deepwater ports) on Georgia's economy in terms of output, income, GDP, employment and taxes. The UGA study separated economic impact into direct economic impact, indirect economic impact, and induced economic impact. Economic data from the Port of Savannah included information from both the Garden City Terminal and the Ocean City Terminal. Likewise, economic data at the Port of Brunswick included information from both Colonel's Island Terminal and Mayor's Point Terminal. Because our report focuses solely on the Garden City Terminal, we had to make assumptions about the data, which are explained in detail below. Additionally, the UGA study separated the economic data for port users and port industry. The study defined the "port industry" as including "economic activity (spending) that involves the transportation of waterborne cargo and port services, including the ports themselves, the companies engaged in deepwater transportation as well as companies that provide ship services, and companies that provide inland transportation of waterborne cargo" (Humphreys 2012). The Garden City Terminal is included as part of the port industry. Port users, on the other hand, are primarily "manufacturers, agricultural firms, wholesalers, distributors, and warehousing and storage firms that use the ports to transport materials and/ or products" (Humphreys 2012).

This section describes how the UGA study was conducted, what assumptions were made, and how specific terms were defined in the report. Stated more simply, port users utilize Georgia's deepwater ports to import and export goods and product. The port user definition excludes transportation expenditures associated with waterborne cargo, however, to avoid double counting economic activity with that of the port industry (Humphreys 2012).

Furthermore, the UGA study separated economic impact into direct economic impact, indirect economic impact, and induced economic impact. All economic activity (spending) generated by port industry, and a portion of spending generated by port users, whose decision to locate, expand, or remain in Georgia hinges on the presence of Georgia's deepwater ports were counted as direct economic impact (Humphreys 2012). Indirect economic impact measures the changes in inter-industry purchases as industries respond to demands triggered by port users and port industry (Humphreys 2012). In a similar study on the economic impact of ports, Pan (2011) defined indirect economic impacts as the "ripple effects from direct final demand changes on related industrial purchases, and induced impacts reflect the effects on regional industries caused by changes in household consumption in response to the effects of direct final demand changes." Induced economic impact measures the "ripples of activity that are created when households spend more due to the increases in their earnings that were generated by the direct and indirect spending" (Humphreys 2012).

Economic output was defined as the gross receipts or sales, minus inventory. Total economic output is the most inclusive and comprehensive measure of economic impact, though it does involve some double counting of economic activity by including the value of inputs produced at other industries. State GDP measures value added, which consists of employee compensation, proprietor income, other property income, and indirect business taxes (Humphreys 2012). Value added is equivalent to gross output less intermediate inputs (Humphreys 2012). The income figure includes all forms of employment income, including wages, salaries, and proprietors' income (Humphreys 2012). The income figure included in the UGA study and thus this report, however, does not include non-wage compensation (Humphreys 2012). Finally, the employment figure includes total wage and salary employees as well as self-employed employees (Humphreys 2012). The employment figure includes both full-time and part-time jobs and is measured in annual average jobs (Humphreys 2012).

The UGA study received its data from the Georgia Ports Authority and other governmental and administrative organizations. The study used two types of economic impact software: (1) MARAD Port Economic Impact ToolKit; and (2) IMPLAN Version 3.0. The Selig Center used the IMPLAN Version 3.0 software to estimate the indirect economic impacts of the ports-related portion of spending by users (Humphreys 2012). Furthermore, the Selig Center used a specialized version of the MARAD Port Economic Impact model to measure the direct, indirect and induced economic impact of spending by the ports industry.

## Appendix 4: Economic Impact Analysis: Port Recovery Periods

### Port Recovery Period after a Category 1 Hurricane

Superstorm Sandy struck New Jersey and New York on October 29, 2012. Sandy hit land with sustained winds of 70 mph and was considered a post-tropical cyclone (approximately a category 1 Hurricane) (Smythe 2013). The Port Authority of New York-New Jersey and the U.S. Coast Guard shut down the New York-New Jersey Port at 6:00 p.m. on October 28, 2012 before the storm made landfall. Hurricane Sandy's storm surge was as high as 14 feet in some parts of New Jersey and New York and inundation levels ranged from 2 to 9 feet around port infrastructure (Blake et al. 2013). The record storm surge, unusually high in part because of a maximum astronomical tidal event, and sustained winds had a significant impact on commercial port operations. Flooding affected these operations in numerous ways, including damage to electrical equipment and electric motors that powered cranes for offloading cargo and truck chassis for transporting cargo beyond the Port (Smythe 2012). Electrical damage to container cranes was a major reason the Container Terminal at the Port was slower to recover than other terminals at the New York-New Jersey Port (Smythe 2012). The loss of electrical power also created security and safety concerns. Security fences were down and the absence of traffic lights raised security risks for employees and drivers at the Port (Smythe 2012). Loss of electricity from saltwater intrusion also disrupted generator use. The Port had electrical generators that were not well-designed to handle saltwater inundation. Diesel generators are better able to handle inundation, but these were not in heavy use at the container terminal during Superstorm Sandy.

Most of the port activity at the Port of New York-New Jersey was shut down for approximately a week, with operations resuming at limited capacity on November 4, 2012, though partial opening began on November 1, 2012 (Smythe 2013). However, the Port's container terminals did not fully reopen on November 4, 2012 because of facility damage and loss of power (Smythe 2013). We therefore estimated that upon re-opening the Port was operating at very limited capacity. We estimated it was operating at 10% of its normal capacity because of the electrical issues and damage to docks noted above. It appears from the literature that the Port of New York-New Jersey recovered quickly after the initial closure, however, so we estimated that after week 2 the container terminal within the Port was already operating at 75% of its pre-Sandy capacity. Reports from three weeks after the hurricane indicated that the Port was still experiencing some delays because of damage to truck chassis and local road networks, which reduced the number of containers able to be drayed off the terminal (OOCL 2012). Therefore, we estimated that the Container Terminal would be operating at 90% of pre-Sandy capacity after week 3. Finally, it appeared that after four weeks the Port was operating at a normal level and therefore the team placed the Port's capacity after week 4 at 100% of its pre-Sandy capacity.

### Port Recovery Period after a Category 3 Hurricane

In 2005, the World Bank commissioned a study to look at the economic impact of Hurricane Ivan on Grenada. Hurricane Ivan struck Grenada on September 7, 2004 as a category 3 Hurricane (World Bank 2005). The Port of St. George's in Grenada was initially overwhelmed by Ivan and remained closed for three days following the storm (World Bank 2005). The international community responded with overwhelming support to this disaster and sent much needed aid and supplies to the country and directly to the Ports Authority. The Ports Authority was able to start accepting supplies and assistance at the port a week following the storm thanks in large part to help from the Trinidadian and St. Lucian Ports Authorities (World Bank 2005). A major impediment to reaching full capacity at the Port of St. George's was the lack of labor available to receive imports and open containers at the Port, which are both labor-intensive processes (World Bank 2005). After an initial recovery effort spurred by international support, the Port had trouble sustaining pre-Ivan operations the weeks following the storm because of damage to all six of its storage sheds on the Port property (World Bank 2005). Three of the storage sheds were rebuilt approximately three months after Hurricane Ivan (World Bank 2005). Storm surge did not cause significant damage because of sea walls that were in place to mitigate the impact of sea waves; wind caused most of the damage at the Port (World Bank 2005). Microburst downdrafts appeared to be the largest cause of damage (World Bank 2005).

The Port recovered to pre-Ivan levels approximately one month after Hurricane Ivan due in large part to the aid from international NGOs and governments (World Bank 2005). At the time the World Bank report was conducted, eight months following Hurricane Ivan's impact, Port of St. George's was handling construction materials (a primary good shipped through the port) "without significant delay" at levels beyond what it was receiving before the hurricane (World Bank 2005).

Hurricane Rita hit made landfall as a category 3 hurricane on the Louisiana and Texas border on September 24, 2005. The eye of Hurricane Rita passed 3.5 miles east of the Port of Port Arthur in Port Arthur, Texas. The economic losses from Rita vary over a wide area (Pan 2011). Port officials at Port of Port Arthur reported that Hurricane Rita caused moderate damage to facilities and cargo at the Port of Arthur (Transportation Board 2008). After the storm, Port Arthur officials moved quickly to assess damages and reopen port facilities. The port's emergency management team was permitted to enter the city on September 28 to start cleaning up the Port. In August of 2006, the Port of Port Arthur reported it was operating at pre-Hurricane Rita levels. Hurricane Rita's total economic damage was estimated at approximately \$10 billion at the Port itself (Pan 2011). Little additional information on specific port recovery times has been published.

Based on information on port recovery times at the Port of St. George's and Port of Port Arthur, and based on the operations, planning and infrastructure in place in and around the Garden City Terminal, the authors estimated a recovery time schedule for the Garden City Terminal in the event of a category 3 hurricane event. As shown in Table 14, the team estimates the port will return to pre-category 3 hurricane levels

approximately 5 weeks after the storm event. As is noted in each section, these closure and reduced capacity figures vary widely depending on the hurricane plans in place at the ports, how well these plans are followed, the proximity of the storm to the port, age of infrastructure, and recovery and relief resources available after a storm makes landfall.

One week after a category 3 hurricane event, the Garden City Terminal would likely operate at 10% capacity and therefore the overall capacity of the Terminal would be reduced by 90%. Two weeks after a category 3 hurricane, the Garden City Terminal would likely be operating at 50% capacity. Because of the Terminal's importance to national economy, relief and recovery efforts would be significant to get the Terminal open and operating at normal levels. Three weeks after a category 3 hurricane, we estimate that the Garden City Terminal would be operating at 75% of its pre-hurricane capacity. Finally, the team estimates that five weeks after a category 5 hurricane the Garden City Terminal would regain full operational capacity. This five week time frame may be optimistic considering that a category 3 event would likely flood and damage critical road and rail infrastructure surrounding the Garden City Terminal. Damage to the container cranes from high wind speeds would extend this recovery time by at least a few weeks, but these additional considerations were too speculative based on available information.

#### **Port Recovery Period after a Category 5 Hurricane**

Hurricane Katrina destroyed one-third of the Port of New Orleans (Grenzeback & Lukmann 2008). The Port of New Orleans is the fifth largest port in the United States in terms of the volume of cargo handled, and includes the twenty-fourth busiest container terminal in terms of volume of TEUs handled in the United States (Grenzeback & Lukmann 2008). During Hurricane Katrina, three major container cranes were damaged (NIST 2006). The container cranes were secured by four hurricane tie-down connections designed to withstand hurricane winds (NIST 2006). Despite this hurricane planning effort, each crane was pushed more than fifty feet inland and severely damaged (NIST 2006). Replacement and repair of container cranes was problematic because the container cranes are not easily transported and have long lead times for assembly and delivery.

In addition to damage to container cranes, the Port of New Orleans severely flooded, canals extending to the Port were silted in, and navigational aids were significantly damaged. As of September 29, 2005, approximately four weeks after Hurricane Katrina struck, 850 of the 1,350 aids to navigation discrepancies identified by the Coast Guard had been repaired with permanent or temporary aids (Grenzeback & Lukmann 2008). Moreover, the Port's 36-foot channel connecting the Port to the Mississippi River-Gulf Outlet was nearly completely silted in from sediment and debris flowing into the channel (Grenzeback & Lukmann 2008). Today, a storm surge barrier blocks access to the Mississippi River-Gulf Outlet and the channel has been closed to maritime shipping since Hurricane Katrina.

Traffic at the Port of New Orleans recovered faster than many expected. The Port of New Orleans welcomed its first vessel approximately two weeks after Hurricane Katrina devastated the Gulf Coast. The Port reached half capacity three and a half months after the storm and would not reach full capacity until much later (Sayre 2006). Six months after Hurricane Katrina, the Port of New Orleans had regained 100% of its pre-hurricane capacity and was averaging 20-22 vessels per week (U.S. Department of Commerce 2006). Though the Port of New Orleans regained its pre-Katrina operational capacity more quickly than most estimated, a report issued by the U.S. Department of Commerce noted that the amount of cargo moving through the Port's facilities fell by approximately 20% compared to pre-Katrina levels of cargo (U.S. Department of Commerce 2006). Moreover, it was estimated that the Port sustained \$100 million in damage, and port users (industry that relied on the port) sustained between \$280 million and \$300 million in damage (Sayre 2006). In addition to massive damage from storm surge and flooding, one of the greatest challenges facing recovery at the Port of New Orleans was in finding labor to clean up and repair damage at the Port. Many of the Port employees' homes had been affected by the hurricane, and many employees relocated to ports on the East Coast for better employment opportunities (Sayre 2006).

When Hurricane Katrina hit the Gulfport Port in Mississippi in 2005, its record-setting 25-foot storm surge knocked down container cranes, blew apart storage sheds, destroyed navigational aids and pushed barges hundreds of feet inland (Wright 2013). Hurricane Katrina destroyed over 300,000 square feet of warehouse space and most of the rail lines into the Port of Gulfport (U.S. Department of Commerce 2006). A year after the storm, the Port of Gulfport was still only operating at 70% of its pre-Katrina capacity (U.S. Department of Commerce 2006). Before Hurricane Katrina the Port had been handling approximately 8 vessels a week; a year after the storm the Port of Gulfport was handling about 4-5 vessels a week (U.S. Department of Commerce 2006). Moreover, some research has indicated that even after five years and over \$250 million in new investments, the Port of Gulfport was still only operating at 80% of its pre-Katrina capacity (Wright 2013).

The team used an average recovery time between the Port of New Orleans and Port of Gulfport after Hurricane Katrina to estimate a port recovery time line in the event of a category 5 storm. The estimation of port recovery times is found below in Table 15. In general, the team estimates the Garden City Terminal would not regain full operations, or 100% capacity, for eight months (32 weeks) after a category 5 Hurricane based on recovery time lines at the Port of Gulfport and the Port of New Orleans. The team also considered factors such as government response and aid, state response and aid, and the port equipment and surrounding infrastructure likely to be damaged in the event of a catastrophic hurricane event in determining the eight-month figure.

The team estimates that one week after a category 5 Hurricane a port would be 100% inoperable. After two weeks, the authors estimated that the port would be 10% operable. It took approximately two weeks for the Port of New Orleans to allow one ship to enter, which we estimated meant that the Port was operating around 10% capacity, or at a 90% reduced capacity compared to normal operating levels. This very limited



operational capacity also includes administrative work, repair to navigation stations, and clean up at the Port. Three weeks after a major category 5 hurricane, we estimate that the Port of Savannah would return to 15% of its pre-hurricane capacity. Thus, the extent of capacity reduced would be 85%. After four weeks, the authors estimate the Port of Savannah will be at 20% of pre-hurricane capacity, which equates to an 80% reduction in capacity. Eight weeks after a category 5 Hurricane, the team estimates that the Port of Savannah will be operating at 35% of normal capacity. After twelve weeks, the Port is estimated to operating at 45% of pre-hurricane capacity. Furthermore, after 16 weeks, the Garden City Terminal would be operating at 55% of its pre-hurricane capacity, and after 20 weeks the Garden City Terminal would be at 65% of pre-hurricane capacity. At 24 weeks, we estimate that the Terminal would be 75% operational. This is a reduction in capacity of 25%. Finally, we estimate that the Terminal would be operating at 90% of its pre-hurricane capacity after 7 months (28 weeks), and would fully recover to pre-hurricane operating capacity (100% capacity) after 32 weeks, or 8 months.

## Appendix 5: Hazus Model

The study team explored using Hazus to quantify the building damage incurred by different categories of hurricanes with and without sea level rise. Hazus is designed to account for social effects and physical damage incurred by hurricanes, flooding, and earthquakes. Hazus has been used to assess the economic impacts of sea level rise and storm surge independently. Storm surge analysis in Hazus is based on combining analysis in two modules: the hurricane module and the flood module. The user inputs the sea level rise at the beginning of the hurricane module, which ostensibly should allow the user to account for sea level rise by comparing model outputs for equivalent scenarios that differ only by sea level. After running the hurricane module with two different sea levels, the user can feed output files into the flood module and run a coastal surge analysis.

The study team considered using Hazus to analyze the effects of sea level rise on storm surge. Hazus has several advantages, including its ability to provide input for flood insurance rate (Scawthorn et al. 2006) and the fact that the study by Keating and Habeeb (2013) used Hazus to estimate storm surge damage at the county level. However, SLOSH also has several disadvantages, including the difficulty in changing in-built assumptions and the extremely long process time for each scenario. Moreover, Hazus has severe compatibility problems, both with other programs and among its hurricane and flood modules. Hazus MH version 2.1 is only compatible with ArcGIS 10.0 service pack 2. The College of Architecture IT department provided a computer system with the appropriate version of windows and ArcGIS for Hazus compatibility, and it troubleshooted other software bugs. However, the Hazus help desk was unable to overcome an incompatibility between the hurricane and software modules by study termination that prevented uploading a digital elevation map in the flood module to scenarios with hurricane module outputs.

## Appendix 6: SLOSH Model and Methodology

The study team estimated flooding using the SLOSH model in the Savannah basin by using built-in scenarios for hurricanes of category 1 through 5 that aggregate the maximum wave heights for a variety of different storm locations, speeds, and directions. The study team overlaid SLOSH flooding output with a parcel file provided by the Chatham County Board of Assessors in ArcGIS to determine the parcels that were fully or partially inundated by storm surge for different hurricane categories at current sea levels. By overlaying the two polygons in ArcGIS, the study team identified the flooded parcels for each scenario and built a table with acreages, building value, land value, and flood height for each. This initial analysis provided the aggregate characteristics for the parcels that were vulnerable to storm surge at current sea levels for five different hurricane categories.

SLOSH does not incorporate sea level rise. Therefore, the study team extrapolated the amount by which sea level rise would increase vulnerability to storm surge by drawing a connection between the maximum wave height produced by SLOSH and the exposure for each scenario. The study team made a new data series of tables for scenarios with sea level rise, and it scaled the values produced in the initial analysis based on the amount by which sea level rise increased maximum storm surge between one scenario and the next.

The method of extrapolating storm surge exposure based on sea level makes several assumptions. It assumes that there is a linear relationship between the maximum wave height and storm surge exposure. This linear relationship may not reflect wave propagation influenced by topography. The extrapolation method also assumes that sea level rise will not change the basic patterns of storm surge, which is an assumption that all SLOSH-based analysis makes. However, storm surge may submerge some barrier islands, which would increase inland vulnerability beyond what is modeled.

The interpolation method has several advantages over GIS-based methods. GIS-based methods are often constrained based on the extent of SLOSH output and are unable to easily assess sea level rise's impact outside of grids produced in SLOSH. Second, GIS-based methods also require the researcher to make assumptions on a case by case basis about how storm surge will propagate to surrounding areas, similar to those assumptions made in a bathtub model.

However, the interpolation method also has several limitations. While it estimates how much sea level rise may increase exposure to storm surge, researchers must rely on other knowledge or models to estimate where those increases are likely to occur. Moreover, the interpolation method requires SLOSH-produced output at higher and lower wave heights. This means that five SLOSH outputs can produce four interpolations. Therefore, the study team was not able to estimate the effects of sea level rise on category 5 storm surge because SLOSH cannot model flooding above category 5.

The study team used outputs of the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model produced by the National Oceanic and Atmospheric Administration (NOAA). SLOSH has several advantages over Hazus. First, it isolates the effects of storm surge compared with wind damage. SLOSH also processes quickly and is compatible with most versions of Windows and other programs. Moreover, SLOSH-based analysis allowed the study team more control over the analytical assumptions. This is more appropriate because SLOSH does not model damage to vehicles, containers, container fields, electrical infrastructure, rubber tired gantry cranes, container cranes, and other port infrastructure that constitute the bulk of the port facilities.

SLOSH estimates storm surge with different hurricane categories. SLOSH offers three analysis options. The first applies historical storms whose paths and wind speeds can be imported. Historical storms were not appropriate because they do not allow for comparisons among equivalent storms of different strengths. The second analytical option allows users to create a storm scenario by setting storm direction, category, tide level, and storm speed. SLOSH produces a flood grid that represents the maximum envelopes of water (MEOW), which is the highest wave height under that scenario. This analytical option is not ideal because storm surge heights would vary by user characteristics, so a hurricane output may not be representative of other hurricanes of that category with a different speed or direction. The third option aggregates the maximum wave heights (MEOWs) for all directions and speeds of a hurricane of a given category into the maximum extent of MEOWs called MOM. The MOM is the maximum wave height of all hurricane scenarios for that water basin and that hurricane category. MOM is most appropriate because it eliminates the need for arbitrarily selected user inputs and it represents the maximum storm surge damage that could be expected with a given hurricane category.

The study team produced five hurricane scenarios in SLOSH for hurricane categories 1 through 5 at high tide. The study team imported the “Savannah/Hilton Head v4” basin in SLOSH. To select the storm type, it clicked the “select-storm” menu and “select storm.” Using high tide and MOMs produces the highest expected wave heights for a hurricane category. The study team also selected the option in SLOSH that automatically subtracts ground level from storm surge heights. Therefore, values in the flood grid represent the expected height of water above ground level in that grid rather than water height above a tidal datum. The study team subtracted land value from storm surge heights by selecting “display,” and “subtract land” in SLOSH before running each model. The study team exported each of the scenarios by selecting “file,” “save data as SHP,” and saving the flooding output as a shapefile for analysis in ArcGIS.

The study team examined ways in which past researchers have used SLOSH output to analyze sea level effects on storm surge. While SLOSH does not account for sea level rise within the model, most perform further spatial analysis on model outputs. For example, Frazier, Wood, Yarnal, and Bauer (2010) analyzed SLOSH storm surge predictions for all five hurricane categories in Sarasota County, FL to approximate the increased extent of surge-related flooding due to sea level rise. Frazier et al. (2010) first

subtracted elevation values in a digital elevation model (DEM) from a rasterized flood grid produced in SLOSH. Those areas where the difference was positive were identified as submerged due to storm surge at current sea levels. To account for 120 centimeters for sea level rise, Frazier et al. (2010) subtracted 120 centimeters from all elevations in the DEM and compared the flood grid with the DEM as it had previously. More grid cells had positive values because of sea level rise, showing that more areas were flooded due to storm surge. Frazier et al. (2010) produced maps in ArcGIS with a raster file showing the additional areas in Sarasota County that were flooded under the sea level rise scenarios compared with the current sea level scenarios. The study team used SLOSH outputs to assess the increased severity of surge floods.

Another method to account for sea level rise effects on storm surge vulnerability is through mathematical extrapolations. Researchers may choose extrapolations for reasons including data availability, the lack of geographically specific methods in the past, or an emphasis on aggregate measures. Nicholls et al. (1999) used a non-linear equation to estimate the increase in storm surge vulnerability in Bangladesh due to sea level rise (Nicholls et al. 1999). The study team derived a similar mathematical model based on the assumption of a linear relationship between water height and storm surge vulnerability, which is explained in appendix 5.

## Appendix 7: ArcGIS Analysis

### Chatham County

SLOSH produces a grid of flood heights for hurricane categories 1 through 5, but it does not itself assess the value of property that is vulnerable to storm surge. Therefore, the study team imported flood shapefiles into ArcGIS to analyze in conjunction with Chatham County Parcel data to determine the economic impact of storm surge at current sea level. ArcGIS is a geographic information system built by ESRI which allows advanced spatial analysis. The study team used a shapefile of Chatham County parcels provided by the Chatham Board of Assessors to analyze with SLOSH-produced flooding shapefiles. The parcel shapefile provided zoning category, property owner, building value, land value, total assessed value, parcel acreage, land use, and many other variables that the study team did not employ. The parcel shapefile provided a rich dataset for Chatham County.

The study team imported the parcel shapefile and the storm surge shapefiles for hurricanes of categories 1 through 5 into '.mxd' ArcGIS files, creating a file for each hurricane scenario.

Importing the flood grids had the following steps.

1. Define the flood grid projection to the North American Datum (NAD) 1927.
2. Add the parcel shapefile.
3. Project the flood grid into the same coordinate system as the parcels, which is Georgia East.

The study team used a series of spatial selections to isolate the parcels that overlapped with the sea storm surge shapefile for each category. These parcels represent those that would be flooded in part or in whole due to storm surge. The flooded parcels' attribute table provided the acreage, building value, land value, and total assessed value likely to be affected at current sea levels by hurricanes of different categories. The study team estimated the average and maximum flood levels by clipping the SLOSH-produced flooding shapefile by the flooded parcels shapefile for each hurricane category. The "statistics" function in the attribute table provided the mean and maximum flooding. The study team built tables to show the acreage, number of parcels, and monetary value of the parcels that overlapped with storm surge grids for each hurricane category at current sea level. This table summarized the county-level storm surge impact.

### Garden City Terminal

Next, the study team assessed flooding at the Garden City Terminal by selecting the single parcel that is the Garden City Terminal and clipping the SLOSH-produced storm surge shapefile to those parcel boundaries. It is important to note that flooding amounts at terminal level are approximations because SLOSH flood grids are very large and lack fine geographic granularity. To account for the lack of data granularity, the study team checked flood heights at the river against the wharf heights provided by the Georgia Ports Authority to make sure that flooding produced in SLOSH represented flooding on terminal property rather than flooding in the adjacent river.



Moreover, the team evaluated flood height on port property as far away from the river as possible to ensure that the height reflected on-land flooding rather than river flooding. The team used the “identify” tool on a flood polygon that was on port property but did not overlap with the Savannah River to produce flood height.

The study team clipped the storm surge grid to the port parcel boundaries for each category, dissolved boundaries among surge grid, and compared the areas of the surge grid and the parcel property to approximate the port area that was flooded for each hurricane category at current sea level. Percentage flooding are more accurate at large scales than at smaller scales because of the large size of the flood grids produced in SLOSH. Therefore, port flooding percentages are rough approximations. However, the method allows the study team to estimate flooding severity when combined with other knowledge about port topography and wharf height.

The study team also produced a table showing the flood height and percent of terminal inundation for each hurricane category at current sea level.

### **Warehouses**

Finally, the study team analyzed warehouse exposure to storm surge at current levels because many goods to and from the Garden City Terminal are processed in local distribution centers. The study team analyzed warehouse exposure to flooding by selecting all parcels in the parcel shapefile with a land use description of “warehouse-detached,” and it manually verified that the category included the port-related warehouses owned by Target and IKEA. Warehouses were spread throughout Chatham County with a large number in northwestern Chatham County near the port. The study team assessed the number of warehouses likely to be affected by storm surge by clipping the warehouse parcels to the SLOSH-produced flood polygons produced for each storm category. It then used the “statistics” tool in the attribute table to obtain the parcel acreages and values for each storm category.

Finally, the study team built an Excel table showing the warehouse exposure to storm surge from each hurricane category at current sea level similarly to how it had for Chatham County and for the Garden City Terminal. These tables did not include the effects of sea level rise, but rather provided the basis for extrapolating increases in vulnerability to storm surge due to sea level rise.

Appendix 9 includes the vulnerability tables for Chatham County, the Garden City Terminal, and warehouses.

## Appendix 8: Linear Extrapolation

Independent research and the past Georgia Coast studio estimated a 100 year sea level increase of one meter, or approximately 3.28 feet (Keating and Habeeb 2012). The research has posited a one meter sea level increase over the next hundred years. Therefore, the research team added one meter to expected surge-related floods produced in SLOSH and analyzed them for key infrastructure.

The study team extrapolated exposure to storm surge with one meter of sea level rise by using the data points and average water levels for the five storm categories as base points and assuming linear exposure increases between one storm category and the next highest. It followed the same procedure for Chatham County, the Garden City Terminal, and warehouses.

First, the study team assessed the percentage of the difference ('PercentageDifference') between maximum flooding of one hurricane category ('MaxFloodingCatA') and the maximum flooding in the next highest storm category ('MaxFloodingCatB'). It assumed a linear relationship in exposure at the two levels of mean flooding. Based on this linearity assumption, the study team multiplied the percentage by the difference ('PercentageDifference') between each variable in the two storm surge categories ('VariableWithoutSLRatCatA' and 'VariableWithoutSLRatCatB'), and added that scaled difference to the storm surge at existing sea level ('VariableWithoutSLRatCatA') using the following equations.

$$\begin{aligned}\text{PercentageDifference} &= 3.28 \text{ feet} / (\text{MaxFloodingCatB} - \text{MaxFloodingCatA}) \\ \text{VariableWithSLRatCatA} &= \text{VariableWithoutSLRatCatA} + \\ &\quad \text{PercentageDifference} * (\text{VariableWithoutSLRatCatB} - \text{VariableWithoutSLRatCatA})\end{aligned}$$

The study team replicated each of the tables that it had built for storm surge vulnerability at the level of the county, terminal, and warehouses, but with vulnerability estimates scaled by the ratio of sea level rise compared with storm surge heights. Appendix 9 shows the complete vulnerability tables.

Linear extrapolation has several advantages compared with analysis in ArcGIS. First, it avoids the need to isolate land that is lower in elevation than SLOSH-based storm surges, which is a very complicated process due to the ways in which wave heights vary based on topographical characteristics. Moreover, the digital elevation map provides much more precise height granularity than SLOSH output, undermining any potential precision increases in the ArcGIS-based approach. Instead, Excel uses datapoints derived from SLOSH itself to extrapolate the relationship between sea level captured in wave heights and each of the variables assessed. As such, the data is internally consistent because it avoids the assumptions required to geographically isolate new areas that might flood without higher sea level.

The Excel-based approach has several weaknesses. First, it does not allow the study team to determine the exact locations that might flood due to high sea level and storm surge. Rather, outputs are aggregated for the geographic unit of analysis. It is possible

to estimate areas of potential flooding by examining the digital elevation map for low-lying areas adjacent to flood grids from SLOSH.

Linear extrapolation depends on several assumptions that may not hold in all circumstances. The first is the linear relationship between each vulnerability variable and maximum wave height. In other words, linear extrapolation assumes that vulnerability by any measure will increase linearly as maximum storm surge heights increase. While this assumption is reasonable on large geographic areas, it may cover a more complex relationship based on land contours, particularly at fine geographic scales.

Linear extrapolation also it assumes that an increase water level due to sea level rise is comparable in characteristics to temporary water level increases due to hurricanes. While this assumption is built into most storm surge and sea level rise analyses, including those using ArcGIS by Frazier et al. (2010), the true relationship is probably more complex. Further research should explore new ways of accounting for sea level rise in storm surge models that account for different characteristics.

Finally, linear interpolation allows estimation of each of the variables with sea level rise for storm categories 1 through 4, but not for category 5. The reason is that interpolation requires point with greater flooding than the case being examined, which does not exist for category 5 storms. Therefore, category 5 variables with sea level rise are marked 'N/A' because they are incalculable. It can be assumed that category 5 storm surge with sea level rise would produce even more severe damage than without.

## Appendix 9: Storm Surge Vulnerability Tables

**Table 31: Chatham County Characteristics**

Chatham County	
Total Area (acres)	258,738
Total Assessed Land Value	\$8,877,078,301
Total Assessed Building Value	\$20,542,508,293

*Source: Chatham County Board of Assessors 2013*

**Table 32: Chatham County Vulnerability to Storm Surge - Current Sea Level**

<b>Affected Parcels</b>	<b>Current Sea Level</b>				
	<b>Cat 1</b>	<b>Cat 2</b>	<b>Cat 3</b>	<b>Cat 4</b>	<b>Cat 5</b>
Number of Parcels	24,988	48,387	87,318	103,605	107,418
Affected Area (acres)	156,903	184,437	235,578	256,647	257,818
Percentage Area	61%	71%	91%	99%	100%
Total Assessed Building Value	\$5,249,243,788	\$9,035,332,800	\$15,464,649,519	\$17,662,242,056	\$18,158,817,431
Mean Building Value	\$210,796	\$187,090	\$177,306	\$170,641	\$169,207
Percentage Building Value	26%	44%	75%	86%	88%
Total Assessed Land Value	\$3,554,160,302	\$5,040,781,496	\$7,377,421,159	\$8,199,476,192	\$8,343,644,581
Mean Assessed Land Value	\$142,726	\$104,377	\$84,584	\$79,218	\$77,748
Percentage Land Value	40%	57%	83%	92%	94%
<b>Flooding</b>					
Max Flooding (feet)	10.3	16.5	21.8	25.8	29.6
Average Flooding (feet)	7.7	11.5	13.6	16.2	19.9

**Table 33: Chatham County Vulnerability to Storm Surge – One Meter of Sea Level Rise**

Affected Parcels	One Meter of Sea Level Rise				
	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
SLR as % of Surge Height Increase	53%	62%	82%	86%	N/A
Number of Parcels	37,366	72,480	100,673	106,896	N/A
Affected Area (acres)	171,469	216,086	252,855	257,657	N/A
Percentage Area	66%	84%	98%	100%	N/A
Total Assessed Building Value	\$7,252,207,007	\$12,436,648,741	\$16,627,246,861.15	\$17,924,946,448	N/A
Mean Building Value	\$198,255	\$181,914	\$173,780	\$169,883	N/A
Percentage Building Value	35%	61%	81%	87%	
Total Assessed Land Value	\$4,340,630,869	\$6,276,939,253	\$7,812,314,789	\$8,275,745,920	N/A
Mean Assessed Land Value	\$122,438	\$93,906	\$81,745	\$78,440	N/A
Percentage Land Value	49%	71%	88%	93%	
<b>Flooding</b>					
Max flooding (feet, one-meter SLR)	13.6	19.8	25.1	29.1	32.9
Average flooding (feet, one-meter SLR)	11	14.7	16.9	19.5	23.2

**Table 34: Flooding at Garden City Terminal Due to Storm Surge at Current Sea Level**

	Current Sea Level				
	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
Water Level above High Tide (feet)	6.8	12.5	17.4	22.7	26.6
Water Level above Ground (feet)	0	1.4	5.5	12	16.2
Percentage of Port Inundated	57%	86%	100%	100%	100%



**Table 35: Flooding at Garden City Terminal Due to Storm Surge with 3 Feet of Sea Level Rise**

	One Meter of Sea Level Rise				
	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
SLR as % of Surge Height Increase	58%	67%	62%	84%	N/A
Water Level above High Tide (feet)	10.1	15.8	20.7	26	29.9
Water Level above Ground (feet)	3.3	4.7	8.8	15.3	19.5
Percentage of Port Inundated	73%	95%	100%	100%	100%

**Table 36: Warehouse Characteristics in Chatham County**

Warehouses in Chatham County	
Total Warehouse Area (acres)	2,147
Total Warehouse Building Value	\$896,204,735
Total Land Value	\$167,121,902

**Table 37: Warehouses in Chatham County Affected by Storm Surge at Current Sea Level**

	Current Sea Level				
	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
Affected Area (acres)	172	762	1,884	2,106	2,112
Percentage Area	8%	36%	88%	98%	98%
Total Assessed Building Value	\$111,977,107	\$390,210,977	\$786,543,254	\$874,600,335	\$875,489,635
Percentage Building Value	12%	44%	88%	98%	98%
Total Assessed Land Value	\$7,713,200	\$54,859,430	\$145,308,949	\$160,551,102	\$161,440,802
Percentage Assessed Value	5%	33%	87%	96%	97%
Max Flooding (feet)	8.7	15.5	21.2	24.4	27.6
Average Flooding (feet)	7.1	6	6.7	10.5	14.3

**Table 38: Warehouses Affected by Storm Surge with One Meter of Sea Level Rise**

	One Meter of Sea Level Rise				
	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
SLR as Water Rise to Next Category	48%	58%	103%	103%	N/A
Affected Area (acres)	456	1,408	2,111	2,112	N/A
Percentage Area	21%	66%	98%	98%	N/A
Total Assessed Building Value	\$246,184,033	\$618,275,826	\$876,801,790	\$875,511,867	N/A
Percentage Building Value	27%	69%	98%	98%	N/A
Total Assessed Land Value	\$30,454,323	\$106,907,565	\$160,932,161	\$161,463,045	N/A
Percentage Assessed Value	18%	64%	96%	97%	N/A
Max Flooding (feet)	12.0	18.8	24.5	27.7	30.9
Average Flooding (feet)	10.4	9.3	10.0	13.8	17.6

## Appendix 10: SLAMM Model Output Tables

**Table 39: SLAMM Model Percentage of Land Cover Change from Base-Year 2000**

This table shows the results of the SAMBI SLAMM model by decade. Percentages are calculated land cover classification changes from 2000 base year.

Percentage Change Since 2000										
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Upland Developed	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Upland Undeveloped	-1.68	-2.09	-4.45	-5.61	-6.30	-7.06	-7.58	-7.95	-8.33	-9.41
Swamp	1.12	0.37	4.03	3.81	2.62	1.28	1.20	1.68	2.12	-1.30
Cypress Swamp	0.11	0.02	0.34	0.30	0.19	0.16	0.18	0.24	0.89	-1.29
Inland Fresh Marsh	1.21	1.17	3.55	2.48	0.62	-3.15	-7.42	-11.35	-15.15	-18.08
Tidal Fresh Marsh	*	*	*	*	*	*	*	*	*	*
Scrub/Shrub Transitional Marsh	896.08	1397.49	2048.00	2948.60	3790.90	4747.85	5184.73	5203.30	5105.21	6251.94
Salt Marsh	-9.63	-14.63	-21.27	-29.67	-37.86	-47.76	-57.11	-61.33	-59.25	-50.00
Mangrove	*	*	*	*	*	*	*	*	*	*
Estuarine Beach	-18.09	-20.78	-24.85	-30.05	-35.14	-39.38	-45.35	-31.82	-36.96	22.97
Tidal Flat	-31.64	-20.97	-5.23	58.25	128.35	252.00	373.07	439.27	434.17	387.44
Ocean Beach	7.34	6.46	17.54	31.12	36.92	40.72	38.79	36.76	28.28	27.66
Ocean Flat	-14.34	-20.84	-29.01	-38.78	-49.04	-61.48	-73.97	-83.77	-86.47	-89.02
Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00	-100.00	-100.00	-100.00	-100.00
Inland Open Ocean	-0.73	-0.74	-3.97	-4.35	-4.68	-5.04	-5.36	-5.64	-5.94	-6.90
Riverine Tidal Open Water	-0.81	-0.80	-55.58	-68.16	-79.35	-81.83	-84.55	-87.17	-88.85	-90.05
Estuarine Open Water	25.82	36.75	53.77	69.29	85.73	103.90	121.45	138.94	154.88	170.61
Tidal Creek	1.17	1.20	1.94	2.05	2.16	2.16	2.23	1.66	1.66	1.84
Open Ocean	1.23	1.50	3.11	4.30	5.27	6.19	7.20	8.14	9.13	10.18
Brackish Water	13.75	20.37	28.70	37.21	41.02	41.74	40.97	35.63	26.08	17.14
Tall Spartina	*	*	*	*	*	*	*	*	*	*
Inland Shore	-71.76	-71.88	-71.87	-71.86	-72.07	-72.05	-73.31	-73.32	-73.32	-73.32
Tidal Swamp	-18.39	-27.57	-39.96	-55.20	-66.52	-78.11	-88.73	-93.96	-94.64	-95.17

Source: South Atlantic Migratory Bird Initiative. "SLAMM Output for DSL-SAMBI Utilizing A1B Emission Scenario, Decadal Predictions 2000-2100 (ESRI GRID)." GIS Data Set. Designing Sustainable Landscapes. Accessed October 21, 2013. <http://www.basic.ncsu.edu/dsl/slr.html>.

**Table 40: SLAMM Model Square Kilometers of Land Cover Change from Base-Year 2000**

This table shows the results of the SAMBI SLAMM model in 20 year increments, which are reported in square kilometers of each land cover type.

Square Kilometers of Land Cover Type						
	2000	2020	2040	2060	2080	2100
Upland Developed	603.65	603.84	603.83	603.83	603.83	603.83
Upland Undeveloped	18245.89	17863.72	17223.06	16957.15	16795.34	16528.68
Swamp	6919.01	6944.29	7182.40	7007.86	7035.22	6829.31
Cypress Swamp	71.71	71.72	71.92	71.82	71.88	70.78
Inland Fresh Marsh	375.18	379.59	384.47	363.35	332.61	307.33
Tidal Fresh Marsh	0.00	0.04	0.04	0.06	0.07	0.06
Scrub/Shrub Transitional Marsh	24.82	371.64	756.59	1203.11	1316.15	1576.39
Salt Marsh	1322.25	1128.76	929.93	690.74	511.37	661.09
Mangrove	0.00	0.03	0.03	0.03	0.03	0.03
Estuarine Beach	11.54	9.14	8.07	6.99	7.87	14.19
Tidal Flat	52.80	41.73	83.56	185.86	284.74	257.37
Ocean Beach	22.22	23.66	29.14	31.27	30.39	28.37
Ocean Flat	16.14	12.78	9.88	6.22	2.62	1.77
Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00
Inland Open Ocean	236.25	234.51	225.97	224.35	222.93	219.94
Riverine Tidal Open Water	43.51	43.16	13.85	7.91	5.58	4.33
Estuarine Open Water	594.80	813.39	1006.92	1212.82	1421.21	1609.61
Tidal Creek	2.55	2.58	2.60	2.60	2.59	2.59
Open Ocean	1352.51	1372.76	1410.68	1436.18	1462.67	1490.14
Brackish Water	507.72	611.15	696.65	719.64	688.61	594.75
Tall Spartina	0.00	0.00	0.00	0.00	0.00	0.00
Inland Shore	12.24	3.44	3.44	3.42	3.26	3.26
Tidal Swamp	402.27	291.36	180.22	88.06	24.29	19.43

Source: South Atlantic Migratory Bird Initiative. "SLAMM Output for DSL-SAMBI Utilizing A1B Emission Scenario, Decadal Predictions 2000-2100 (ESRI GRID)." GIS Data Set. Designing Sustainable Landscapes. Accessed October 21, 2013. <http://www.basinc.ncsu.edu/dsl/slr.html>

## References

### Port of Savannah

- Ashar, Asaf. 2006. "Revolution #4." *Containerisation International* 39 (12).  
<http://trid.trb.org/view.aspx?id=802868>.
- Bank of America Merrill Lynch. 2013. "Get Ready for the Big Ships."  
[http://corp.bankofamerica.com/documents/10157/67594/MISC-04-13-2648\\_Fortune\\_Custom\\_Content\\_Panama\\_Canal\\_FINAL\\_051613.pdf](http://corp.bankofamerica.com/documents/10157/67594/MISC-04-13-2648_Fortune_Custom_Content_Panama_Canal_FINAL_051613.pdf).
- Barbash, Fred and Bohan, Caren. 2013. "Insight: U.S. Congress finds cure for gridlock in water." *Reuters*, October 29. <http://www.reuters.com/article/2013/10/29/us-usa-congress-water-insight-idUSBRE99S04Y20131029>
- Becker, A., S. Inome, M. Fischer, and B. Schwegler. 2012. "Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators." *Climatic Change* 110: 5-29.
- Bhuiyan, Md Javed Abdul Naser, and Dushmanta Dutta. 2012. "Assessing Impacts of Sea Level Rise on River Salinity in the Gorai River Network, Bangladesh." *Estuarine, Coastal and Shelf Science* 96: 219–227.
- Bigano, Andrea and Francesco Bosello and Roberto Roson and Richard S. J. Tol, Economy-Wide Estimates of the Implications of Climate Change: A Joint Analysis for Sea Level Rise and Tourism (November 1, 2006). FEEM Working Paper No. 135.2006; CMCC Research Paper No. 5. Available at SSRN: <http://ssrn.com/abstract=944480> or <http://dx.doi.org/10.2139/ssrn.944480.0>
- BIMCO. 2012. "CONTAINER SHIPPING - LOWERED SUPPLY MAKES SENSE IN RESPONSE TO THE LEAKING DEMAND", October 10.  
[https://www.bimco.org/en/reports/market\\_analysis/2012/1017\\_containersmoo2012-5.aspx](https://www.bimco.org/en/reports/market_analysis/2012/1017_containersmoo2012-5.aspx).
- Board, Marine. 1987. *Responding to Changes in Sea Level: Engineering Implications*. National Academies Press.  
<http://books.google.com/books?hl=en&lr=&id=lwRp8UGaan8C&oi=fnd&pg=PA1&dq=Responding+to+changes+in+sea+level:+engineering+implications&ots=dLTJgxACKA&sig=acLeS2P09LHq0L42dvQ60X1JrEc>.
- Boile, Maria. 2012. "Intermodal Transportation: Moving Freight in a Global Economy." *Journal of the Transportation Research Forum* 51.  
<http://journals.oregondigital.org/trforum/article/download/2841/2446>.
- Borgerson, Scott. 2013. "The Coming Arctic Boom: As the Ice Melts, the Region Heats Up." [http://heinonlinebackup.com/hol-cgi-bin/get\\_pdf.cgi?handle=hein.journals/fora92&section=66](http://heinonlinebackup.com/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/fora92&section=66).
- Campbell, Gillam, Marvin Clermont, Kathryn Colberg, Richelle Gosman, Anna Rose Harkness, Amy Moore Hagens, Paul Lorenc, Dzung Nguyen, Jennifer Yun, and Joy Zhou. 2012. "Tracking the Effects of Sea Level Rise in Georgia's Coastal Communities." <http://smartech.gatech.edu/handle/1853/48711>.
- Chang, Sun Woo, T. Prabhakar Clement, Matthew J. Simpson, and Kang-Kun Lee. 2011. "Does Sea-level Rise Have an Impact on Saltwater Intrusion?" *Advances in Water Resources* 34 (10): 1283–1291.
- "China Cruise Liner Crashes into Bridge." 2012. *Telegraph.co.uk*, May 25, sec. worldnews.

- <http://www.telegraph.co.uk/news/worldnews/asia/china/9290388/China-cruise-liner-crashes-into-bridge.html>.
- Conway, CRE, and MAI. 2013. "North American Port Analysis: Beyond post-Panamax Basics to Logistics." Insider's Perspective.  
[http://www.cre.org/memberdata/pdfs/North\\_American\\_Port\\_Analysis.pdf](http://www.cre.org/memberdata/pdfs/North_American_Port_Analysis.pdf).
- Cudahy, Brian J. 2006. "The Containership Revolution: Malcom McLean's 1956 Innovation Goes Global." *TR News* 246. <http://trid.trb.org/view.aspx?id=793327>.
- Day, Frances. "Principles of Impact Analysis and IMPLAN Applications."
- DNV. 2011. "Panama Canal Expansion - What Will Be Required for New Panamax Vessels?", May 13.  
[http://www.dnv.com/industry/maritime/publicationsanddownloads/publications/newsletters/technical\\_regulatory/2011/panamacanalexpansion.asp](http://www.dnv.com/industry/maritime/publicationsanddownloads/publications/newsletters/technical_regulatory/2011/panamacanalexpansion.asp).
- Emanuel, Kerry. 2005. "Increasing Destructiveness of Tropical Cyclones over the Past 30 Years." *Nature* 436 (7051): 686–688.
- Federal Emergency Management Agency. 2013. "Hazus." <http://www.fema.gov/hazus>.
- Federal Highway Administration. 2007. "Mitigation Strategies for Design Exceptions. The 13 Controlling Criteria."  
<http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/index.htm>
- . 2011. Highway Statistics 2011. *Highway Statistics Series*.  
<http://www.fhwa.dot.gov/policyinformation/statistics/2011/>
- Florida Department of Transportation. 2011. "Bridge Costs." *Transportation Costs Report*. <http://www.dot.state.fl.us/planning/policy/costs/Bridges.pdf>
- Fitzgerald, D.M., M.S. Fenster, B.A. Argow, and I. Buynevich. 2008. "Coastal Impacts Due to Sea-Level Rise." *Annual Review Earth Planet Sciences* 36: 601-647.
- Fonteh, M., L.S. Esteves, and W.R. Gehrel. 2009. "Mapping and valuation of ecosystems and economic activities along the coast of Cameroon: implications of future sea level rise." *Coastline Reports* 13: S. 47-63.
- Frazier, Tim G., Nathan Wood, Brent Yarnal, and Denise H. Bauer. 2010. "Influence of Potential Sea Level Rise on Societal Vulnerability to Hurricane Storm-Surge Hazards, Sarasota County, Florida." *Applied Geography* 30 (4) (December): 490–505. doi:10.1016/j.apgeog.2010.05.005.
- Georgia Department of Transportation. 2011. "Georgia Statewide Freight & Logistics Plan - Marine Modal Profile - Final Report". Georgia Department of Transportation, Office of Planning.  
<http://www.dot.ga.gov/Projects/programs/georgiafreight/logisticsplan/Documents/Plan/MarineModal-Task3.pdf>.
- Georgia Emergency Management Agency. 2013. "Georgia Hurricane Plan." Georgia Emergency Operations Plan.  
<http://www.gema.ga.gov/content/atts/prepare/Plans%20and%20Maps/Plan%20Library/2010%20GEOP%20IA-A%20Hurricane%20CONPLAN.pdf>.
- Georgia Ports Authority. 2012. "Interstate & Rail - Satisfying Market Demand."  
<http://www.gaports.com/Facilities/GardenCityTerminal/InterstateRail.aspx>.
- . 2013. "GPA Reports Highest Tonnage on Record", May 20.  
<http://www.gaports.com/corporate/tabid/379/xmmid/1097/xmid/8427/xmview/2/default.aspx>.



- . 2013a. "GPA By the Numbers." Accessed October 11.  
<http://www.gaports.com/SalesandMarketing/MarketingBusinessDevelopment/GPABytheNumbers.aspx>.
- . 2013b. "Specifications - Garden City Terminal." Accessed October 10.  
<http://www.gaports.com/Facilities/GardenCityTerminal/Specifications.aspx>.
- . 2013c. "Port of Savannah." <http://www.gaports.com/portofsavannah.aspx>.
- "Global Warming: The Vanishing North." 2012. *The Economist*, June 16.  
<http://www.economist.com/node/21556921>.
- Gordon, Peter, I. I. Moore, E. James, Harry W. Richardson, and Qisheng Pan. 2006. "The Costs of a Terrorist Attack on Terminal Island at the Twin Ports of Los Angeles and Long Beach."  
[http://research.create.usc.edu/nonpublished\\_reports/33/](http://research.create.usc.edu/nonpublished_reports/33/).
- Grenzeback, Lance R., and Andrew T. Lukman. 2008. "Case Study of the Transportation Sector's Response to and Recovery from Hurricane's Katrina and Rita." Transportation Research Board.
- Hallegatte, S., N. Ranger, O. Mestre, P. Dumas, J. Morlot, C. Herweijer, and R. Muir Wood. 2011. "Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen." *Climatic Change* 104: 113-137.
- Heberger, M., H. Cooley, P. Herrera, P. H. Gleick, and E. Moore. 2011. "Potential impacts of increased coastal flooding in California due to sea-level rise." *Climate Change* 109: S. 229-249.
- Hoel, L. A., G. Guiliano, and M. D. Meyer. 2011. *Intermodal Transportation: Moving Freight in a Global Economy*. Washington, DC: Eno Transportation Foundation, Inc.
- Humphreys, J. & Selig Center for Economic Growth, Terry College of Business, University of Georgia. 2012. "The Economic Impact of Georgia's Deepwater Ports on Georgia's Economy in FY 2011."  
[http://www.terry.uga.edu/media/documents/selig/ga\\_ports\\_study\\_2011.pdf](http://www.terry.uga.edu/media/documents/selig/ga_ports_study_2011.pdf)
- ICF International. "Planning for Climate Change Impacts at U.S. Ports." Paper presented at the Transportation Research Board Annual Meeting, Washington, D.C., 2009.
- Keating, Larry and Dana Habeeb. 2012. "Tracking the Effects of Sea Level Rise in Georgia's Coastal Communities." <http://smartech.gatech.edu/handle/1853/48711>.
- Knutson, Thomas R., John L. McBride, Johnny Chan, Kerry Emanuel, Greg Holland, Chris Landsea, Isaac Held, James P. Kossin, A. K. Srivastava, and Masato Sugi. 2010. "Tropical Cyclones and Climate Change." *Nature Geoscience* 3 (3): 157–163.
- Koetse, Mark J. & Piet Rietveld. 2009. "The impact of climate change and weather on transport: An overview of empirical findings." *Transportation Research Part D* 14 (3): 205-221.
- Knutson, T. R., J. L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, and M. Sugi. 2010. "Tropical cyclones and climate change." *Nature Geoscience*, 3 (3): 157-163.
- Landers, Mary. 2013. "Savannah harbor deepening lawsuits settled, new hurdles emerge." *Savannah Morning News*, May 30.

- [http://savannahnow.com/news/2013-05-29/savannah-harbor-deepening-lawsuits-settled-new-hurdles-emerge#.UpK\\_5-KKIoM](http://savannahnow.com/news/2013-05-29/savannah-harbor-deepening-lawsuits-settled-new-hurdles-emerge#.UpK_5-KKIoM)
- Marine Board. 1987. *Responding to Changes in Sea Level: Engineering Implications*. National Academies Press.  
<http://books.google.com/books?hl=en&lr=&id=lwRp8UGaan8C&oi=fnd&pg=PA1&dq=Responding+to+changes+in+sea+level:+engineering+implications&ots=dLTJgxACkA&sig=acLeS2P09LHq0L42dvQ60X1JrEc>.
- Nathanael Massey and ClimateWire. 2013. "New Model Predicts Uptick in Hurricane Intensity and Frequency." *Scientific American*, July 9.  
<http://www.scientificamerican.com/article.cfm?id=new-model-predicts-uptick-hurricane-intensity-frequency>.
- National Hurricane Center. 2013. "Sea, Lake, and Overland Surges from Hurricanes (SLOSH)". National Weather Service. <http://www.nhc.noaa.gov/surge/slosh.php>.
- National Institutes of Standards and Technology (NIST). 2006. "Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report." National Institute of Standards and Technology.
- National Oceanic and Atmospheric Administration. 2013. "Mean Sea Level Trend. 8670870 Fort Pulaski, Georgia." *Tides & Currents*.  
[http://tidesandcurrents.noaa.gov/sltrends/sltrends\\_station.shtml?stnid=8670870](http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8670870).
- Smythe, Tiffany C. 2013. "Assessing the Impacts of Hurricane Sandy on the Port of New York and New Jersey's Maritime Responders and Response Infrastructure." National Science Foundation. Quick Response Report No. 238. Final Report to the University of Colorado Natural Hazards Center Quick Response Grant Program, Grant CMMI1030670.
- Naval Research Laboratory. 2008. *Hurricanes Haven Handbook*.  
[http://www.nrlmry.navy.mil/port\\_studies/tr8203nc/savannah/text/frame.htm](http://www.nrlmry.navy.mil/port_studies/tr8203nc/savannah/text/frame.htm).
- Ng, A. K., S. L. Chen, S. Cahoon, B. Brooks, and Z. Yang. 2013. "Climate change and the adaptation strategies of ports: The Australian experiences." *Research in Transportation Business & Management*.
- Nicholls, Robert J., Frank M.J. Hoozemans, and Marcel Marchand. 1999. "Increasing Flood Risk and Wetland Losses due to Global Sea-Level Rise: Regional and Global Analyses." *Global Environmental Change* 9, Supplement 1 (October): S69–S87. doi:10.1016/S0959-3780(99)00019-9.
- Nurse-Bray, M., B. Blackwell, B. Brooks, M.L. Campbell, L. Goldsworthy, H. Pateman, I. Rodrigues, M. Roome, J.T. Wright, J. Francis, and Chad L. Hewitt. 2013. "Vulnerabilities and adaptation of ports to climate change." *Journal of Environmental Planning and Management*, 56 (7): 1021-1045.
- Nurse-Bray, et al. *Journal of Environmental Planning and Management*.
- Pan, Qisheng. 2010a. "Economic Losses from a Hypothetical Hurricane Event in the Houston-Galveston Area." *Natural Hazards Review* 12 (3): 146–155.
- Panama Canal Authority. 2006. "Proposal for the Expansion of the Panama Canal: Third Set of Locks Project."  
<http://www.pancanal.com/eng/plan/documentos/propuesta/acp-expansion-proposal.pdf>.
- Pelletier, Sebastien, and Frederic Lasserre. 2012. "Arctic Shipping: Future Polar Express Seaways? Shipowners' Opinion." *J. Mar. L. & Com.* 43: 553–581.

- “REUTERS SUMMIT-Maersk Line Sees Shipping Overcapacity for Five Years.” 2013. *Reuters*, October 2. <http://www.reuters.com/article/2013/10/02/nordic-summit-maersk-idUSL6N0HS2MD20131002>.
- Rodrigue, Jean-Paul. 2010a. *Factors Impacting North American Freight Distribution in View of the Panama Canal Expansion*. Van Horne Institute. [http://people.hofstra.edu/jean-paul\\_rodrigue/downloads/Panama%20Canal%20Study%202011%20Final.pdf](http://people.hofstra.edu/jean-paul_rodrigue/downloads/Panama%20Canal%20Study%202011%20Final.pdf).
- . 2010b. “Maritime Transportation: Drivers for the Shipping and Port Industries.” *International Transport Forum*. <http://storage.globalcitizen.net/data/topic/knowledge/uploads/20120218153027579.pdf>.
- “Savannah Captain of the Port Zone. Port Hurricane Preparedness Guide.” 2013. [http://www.savannahmaritime.com/index\\_files/Port%20Hurricane%20Preparedness%20Guide%202013%20COMB.pdf](http://www.savannahmaritime.com/index_files/Port%20Hurricane%20Preparedness%20Guide%202013%20COMB.pdf).
- Sayre, Alan. 2013. “New Orleans Port Is Getting over Katrina - The New York Times.” Accessed October 11. [http://www.nytimes.com/2006/01/03/business/worldbusiness/03iht-port.html?\\_r=0](http://www.nytimes.com/2006/01/03/business/worldbusiness/03iht-port.html?_r=0).
- Scawthorn, Charles, Neil Blais, Hope Seligson, Eric Tate, Edward Mifflin, Will Thomas, James Murphy, and Christopher Jones. 2006. “HAZUS-MH Flood Loss Estimation Methodology. I: Overview and Flood Hazard Characterization.” *Natural Hazards Review* 7 (2): 60–71.
- Smith, Laurence C., and Scott R. Stephenson. 2013. “New Trans-Arctic Shipping Routes Navigable by Midcentury.” *Proceedings of the National Academy of Sciences* 110 (13): E1191–E1195.
- Sterr, Horst. 2008. “Assessment of Vulnerability and Adaptation to Sea Level Rise for the Coastal Zone of Germany.” *Journal of Coastal Research* 24 (2): 380-393.
- Tebaldi, Claudia, Benjamin H. Strauss, Chris E. Zervas. 2012. “Modelling sea level rise impacts on storm surges along US coasts.” *Environmental Research Letters* 7 (1).
- Thatcher, C.A., J. C. Brock, and E.A. Pendleton. 2013. “Economic Vulnerability to sea level rise along the Northern U.S. Gulf Coast.” *Journal of Coastal Research* 63: 234-243.
- The World Bank. 2005. “Grenada: A Nation Rebuilding. An assessment of reconstruction and economic recovery one year after Hurricane Ivan.”
- Titus, Jim. 2002. “Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?” *The Potential Impacts of Climate Change on Transportation*: 135.
- Transportation Research Board. 2008. “Potential Impacts of Climate Change on U.S. Transportation.” The National Academies Press.
- U.S. Army Corps of Engineers. 2012. “Final Environmental Impact Statement for Savannah Harbor Expansion Project Chatham County, Georgia and Jasper County, South Carolina.” Savannah, GA. <http://www.sas.usace.army.mil/Missions/CivilWorks/SavannahHarborExpansion/FinalEnvironmentalImpactStatement.aspx>.

- U.S. Department of Commerce, Economics and Statistics Administration. 2006. "The Gulf Coast: Economic Impact & Recovery One Year after the Hurricanes." <http://www.esa.doc.gov/sites/default/files/reports/documents/oct2006.pdf>
- United Nations. 2013. "Consequence of Climate Change." <http://www.un.org/wcm/content/site/climatechange/pages/gateway/the-science/consequences-for-the-future>.
- Watson, Robert T., Marufu C. Zinyowera, and Richard H. Moss. 1998 "The regional impacts of climate change: an assessment of vulnerability." Cambridge University Press.
- Wong, Andy, and Erhan Kozan. 2009. "Optimization of Container Process at Seaport Terminals." *Journal of the Operational Research Society* 61 (4): 658–665.
- Yoskowitz, David W., James Gibeaut, and Ali McKenzie. 2009. "The Socio-Economic Impact of Sea Level Rise in the Galveston Bay Region." *Corpus Christi, TX: A Report for the Environmental Defense Fund. Harte Research Institute for Gulf of Mexico Studies, Texas A&M University*. [https://www.edf.org/sites/default/files/9901\\_EDF\\_Sea\\_Level\\_Rise\\_Report.pdf](https://www.edf.org/sites/default/files/9901_EDF_Sea_Level_Rise_Report.pdf).

## Darien

- Alber, Merryl, and Joan E. Sheldon. 1999. "Trends in Salinities and Flushing Times of Georgia Estuaries." *Proceedings of the 1999 Georgia Water Resources Conference*, March 30.
- Bin, O., B. Poulter, C.F. Dumas and J.C. Whitehead. 2011. "Measuring the impact of sea-level rise on coastal real estate: A hedonic property model approach." *Journal of Regional Science* 51 (4): 751-767.
- Bureau of Economic Analysis, U.S. Department of Labor, "Travel and Tourism Spending Decelerated in the Second Quarter of 2013," last modified September 20, 2013, <http://www.bea.gov/newsreleases/industry/tourism/tournewsrelease.htm>
- Bureau of Labor Statistics, U.S. Department of Labor, "Occupational Outlook Handbook, 2012-13 Edition, Fishers and Related Fishing Workers." Accessed November 15, 2013. <http://www.bls.gov/ooh/farming-fishing-and-forestry/fishers-and-related-fishing-workers.htm>
- California State Parks. Division State Parks- Division of Boating and Waterways. "The Economic Costs of Sea-Level Rise to California Beach Communities." <http://www.dbw.ca.gov/PressRoom/2011/110913CalifSeaLevelRise.aspx>
- Clemo, K. 2008. "Preparing for climate change: insurance and small business." *Geneva Papers on Risk & Insurance*, 33 (1): 110. doi:<http://dx.doi.org/10.1057/palgrave.gpp.2510160>
- Clough, Jonathan. 2010. "The SLAMM Model." Lecture Slides, March 18. Warren Pinnacle Consulting. Accessed November 16, 2013. [http://warrenpinnacle.com/prof/SLAMM/SLAMM\\_Presentation](http://warrenpinnacle.com/prof/SLAMM/SLAMM_Presentation).
- Clough, Jonathan, Richard Park, and Roger Fuller. 2010. "SLAMM 6 beta Technical Documentation." Warren Pinnacle Consulting.
- Coastal Georgia Regional Development Center. 2007. "McIntosh County and the City of Darien Joint Comprehensive Plan Community Assessment," October. Brunswick, GA. Accessed October 12, 2013.

- Cooley, Dana Robert. 2003. "Cultural models and fishing knowledge: A case study of commercial blue crab fishermen in Georgia, USA." Accessed September 2013. [http://athenaeum.libs.uga.edu/xmlui/bitstream/handle/10724/6655/cooley\\_dana\\_r\\_200305\\_phd.pdf?sequence=1](http://athenaeum.libs.uga.edu/xmlui/bitstream/handle/10724/6655/cooley_dana_r_200305_phd.pdf?sequence=1)
- Costanza, R., M. Grasso, R. D'Arge, R. De Groot, S. Farber, B. Hannon, and M. Van Den Belt, et al. 1997. "The value of the world's ecosystem services and natural capital." *Nature* 387, (6630): 253-260.
- Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H.Y. Guo, and M. Machmuller. 2009. "Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services." *Frontiers in Ecology And The Environment* 7 (2): 73-78. Science Citation Index, EBSCOhost Accessed October 12, 2013.
- Ecological Planning Group. 2008. "Comprehensive Plan Partial Update: City of Darien," July. Accessed October 12, 2013. [http://www.dca.state.ga.us/development/planningqualitygrowth/Adopted%20Local%20Comprehensive%20Plans/2008/DarienCi.Prtl\\_2008.pdf](http://www.dca.state.ga.us/development/planningqualitygrowth/Adopted%20Local%20Comprehensive%20Plans/2008/DarienCi.Prtl_2008.pdf)
- F.E.M.A. 2013. "Biggert Waters flood insurance reform: Impact of National Flood Insurance Program (NFIP) changes." [http://www.riema.ri.gov/prevention/floods/bw12\\_sec\\_205\\_207fact\\_sheet\\_04\\_2013.pdf](http://www.riema.ri.gov/prevention/floods/bw12_sec_205_207fact_sheet_04_2013.pdf).
- Frechtling, Douglas and Smeral, Egon. "6 Measuring and Interpreting the Economic Impact of Tourism: 20/20 Hindsight and Foresight" <http://home.gwu.edu/~frechtli/material/FrechtlingSmeral2020.pdf>
- Gelin, Agnès, et al. 2001. "Can Salinity Changes Affect Reproductive Success in the Brown Shrimp Crangon Crangon?" *Journal of Crustacean Biology* 21(4): 905-911. BioOne. Accessed September 23, 2013. <http://www.bioone.org/doi/full/10.1651/0278-0372%282001%29021%5B0905%3ACSCARS%5D2.0.CO%3B2>.
- Georgia Department of Natural Resources Division of Coastal Resources. 2013. *Georgia's Commercial Saltwater Fishing Regulation*, March. <http://www.coastalgadnr.org/sites/uploads/crd/2013CommRegWeb.pdf>
- Graitcer, Phillip. 2012. "US Jellyfish Land on Asian Dinner Tables." *Voice of America*, March. Accessed September 20 2013. <http://www.voanews.com/content/us-jellyfish-land-on-asian-dinner-tables-143681576/179134.html>.
- Griffin, DuBose B, and Murphy, Thomas M. "Cannonball Jellyfish: *Stomolophus meleagris*." South Carolina Department of Natural Resources. Accessed September 20 2013. <http://www.dnr.sc.gov/cwcs/pdf/Cannonballjellyfish.pdf>.
- Grosvenor, Tiffany, Leandra Harewood and Winston Moore. "The Supply Side Effects of Climate Change on Tourism." <http://sta.uwi.edu/conferences/09/salises/documents/W%20Moore.pdf>
- Gunn, Clare A., *Tourism Planning: Basics, Concepts, and Cases* (New York: Routledge, 2002) [http://books.google.com/books?hl=en&lr=&id=6S6e44VhObMC&oi=fnd&pg=PR9&dq=importance+of+tourism+planning&ots=Rc-OjnouJ4&sig=\\_91hyY6CGPrkYuYHpwoqSZjmakA#v=onepage&q=importance%20of%20tourism%20planning&f=false](http://books.google.com/books?hl=en&lr=&id=6S6e44VhObMC&oi=fnd&pg=PR9&dq=importance+of+tourism+planning&ots=Rc-OjnouJ4&sig=_91hyY6CGPrkYuYHpwoqSZjmakA#v=onepage&q=importance%20of%20tourism%20planning&f=false)
- Hall, Colin Michael, James E. S. Higham. "Tourism, Recreation, and Climate Change."

- <http://books.google.com/books?id=7nNEFApnJAcC&pg=PT68&lpg=PT68&dq=tourism+sea+level+rise&source=bl&ots=Me32tS2FKh&sig=-hBqHaOHqyyU44vzZBs4zZd8ILQ&hl=en&sa=X&ei=eKR3Ut3VELLJsQSo44C4BA&ved=0CDsQ6AEwADgK#v=onepage&q=tourism%20sea%20level%20rise&f=false>
- Hall, CM. "Trends in ocean and coastal tourism: the end of the last frontier?" *Ocean & Coastal Management*, Volume 44, Issues 9–10, (2001): 601-618  
[http://dx.doi.org/10.1016/S0964-5691\(01\)00071-0](http://dx.doi.org/10.1016/S0964-5691(01)00071-0)
- Higinbotham, Carrie B. 2004. "Analysis of Tidal Marsh Vegetation Patterns in Two Georgia Estuaries Using Aerial Photography and GIS," August. *Estuaries* 27 (4): 670–683.
- Howe, Jeffrey C., Richard K. Wallace, and F. Scott Rikard. 1999. "Habitat Utilization by Postlarval and Juvenile Penaeid Shrimps in Mobile Bay, Alabama." *Estuaries* 4: 971. JSTOR Life Sciences, EBSCOhost. Accessed October 11, 2013.
- Huntington, H., E. Goodstein and E. Euskirchen. 2012. "Towards a tipping point in responding to change: Rising costs, fewer options for arctic and global societies." *AMBIO - A Journal of the Human Environment* 41 (1): 66-74.
- Jennings, Simon. "Coastal tourism and shoreline management," *Annals of Tourism Research* Volume 31, Issue 4, October 2004, Pages 899–922  
<http://www.sciencedirect.com/science/article/pii/S0160738304000684>
- Kenchington, Richard. "Tourism in coastal and marine environments—a recreational perspective," Volume 19, Issue 1, 1993, Pages 1–16 <http://www.sciencedirect.com/science/article/pii/0964569193900738>
- Kirshen, P., S. Merrill, P. Slovinsky and N. Richardson. 2012. "Simplified method for scenario-based risk assessment adaptation planning in the coastal zone." *Climatic Change* 113 (3/4): 919-31.
- Landers, Mary. 2011. "Coastal Georgia Shrimpers Turn to Jellyfish to Make Money." *Savannah Morning News*, May 15. Accessed September 13, 2013.  
<http://savannahnow.com/news/2011-05-15/coastal-georgia-shrimpers-turn-jellyfish-make-money#.UjNlpzasiFy>.
- Landers, Mary. 2013. "Black Gill Disease Threatens Georgia Shrimp." *Savannah Morning News*, October 30. Accessed November 13, 2013.  
<http://savannahnow.com/news/2013-10-30/black-gill-disease-threatens-georgia-shrimp#>.
- Leatherman, Stephen P. Volume 75, 2001, Pages 181–223 "Social and economic costs of sea level rise." <http://www.sciencedirect.com/science/article/pii/S0074614201800115>.
- MacArthur, Ron. Cape Gazette of Lewes, Delaware. Original Publication Date: May 31, 2013. "Sussex abstains on sea level rise"  
<http://www.smalltownnews.com/article.php?catname=Business&pub=Cape%20Gazette&aid=143701>.
- McLeod, Harriet. 2013. "Parasite Depletes Wild Shrimp Haul Off Southeast Atlantic Coast." *Reuters*, November. Accessed November 3, 2013.  
<http://www.reuters.com/assets.print?aid=USBRE9A207R20131103>.



- Merrill, S., P. Kirshen, D. Yakolveff, S. Lloyd, C. Keeley, B. Hill. 2012. "Coast in action: 2012 projects from New Hampshire and Maine." Portland, Maine: New England Environmental Finance Center
- McInnes, M.L., K. J. E. Walsh, G. D. Hubbert, T. Beer, "Impact of Sea-level Rise and Storm Surges on a Coastal Community." October 2003, Volume 30, Issue 2, pp 187-207. <http://link.springer.com/article/10.1023/A:1026118417752#page-1>
- Michael, J.A. 2007. "Episodic flooding and the cost of sea-level rise." *Ecological Economics : The Transdisciplinary Journal of the International Society for Ecological Economics* 63 (1): 149-159.
- NOAA. "Salinity." *Ocean Service Education*. Accessed September 25, 2013. <http://www.noaa.gov>
- Ponce-Palafox, J., C.A. Martinez-Palacios, and L.G. Ross. 1997. "The effects of salinity and temperature on the growth and survival rates of juvenile white shrimp, *Penaeus vannamei*, Boone, 1931." *Aquaculture* 157 (1-2): 107-115. Scopus®, EBSCOhost. Accessed November 16, 2013.
- Porter, Dwayne, Don Edwards, Geoff Scott, Ben Jones, and W. Scott Street. 1997. "Assessing the Impacts of Anthropogenic and Physiographic influences on Grass Shrimp in Localized Salt-Marsh Estuaries." *Aquatic Botany* 58: 289-306.
- Riggs, Stanley R., Dorothea V. Ames, Stephen J. Culver and David J. Mallinson. "Betting on a shore thing." <http://www.businessnc.com/articles/2011-09/betting-on-a-shore-thing-category/>
- Sagoe-Addy Kate, and Kwasi Appeaning Addo. March 2013, Volume 17, Issue 1, pp 155-166 "Effect of predicted sea level rise on tourism facilities along Ghana's Accra coast." <http://link.springer.com/article/10.1007%2Fs11852-012-0227-y#page-1>
- Sartwell, Tim. 2009. "What Can Be Done To Save The East Coast Blue Crab Fishery?" May. Accessed September 20 2013. [http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/1014/tws2\\_mp\\_final.pdf?sequence=1](http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/1014/tws2_mp_final.pdf?sequence=1)
- Saoud, Patrick, and D. Allen Davis. 2003. "Salinity Tolerance of Brown Shrimp *Farfantepenaeus aztecus* as it Relates to Postlarval and Juvenile Survival, Distribution, and Growth in Estuaries." *Estuaries* 26 (4A): 970-974.
- Science Daily. 2003. "UGA Researchers Explain Recent Decline In Georgia's Blue Crab Population," December.
- Scotta Daniel, Murray Charles Simpson & Ryan Sima. Volume 20, Issue 6, 2012. "The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise." <http://www.tandfonline.com/doi/abs/10.1080/09669582.2012.699063#preview>
- Shenker, Jonathan M. 2009. "Effects of Climate Change on Fishery Species in Florida." *AIP Conference Proceedings* 1157 (1): 39-47.
- Simas, T., J.P. Nunes, and J.G. Ferreira. 2001. "Effects of Global Climate Change on Coastal Salt Marshes." *Ecological Modelling* 139.
- Sookram Sandra. "The Impact of Climate Change on the Tourism Sector in Selected Caribbean Countries." <http://www.eclac.cl/publicaciones/xml/3/38253/lcarl.245part4.pdf>

- South Atlantic Migratory Bird Initiative. "SLAMM Output for DSL-SAMBI Utilizing A1B Emission Scenario, Decadal Predictions 2000-2100 (ESRI GRID)." GIS Data Set. Designing Sustainable Landscapes. Accessed October 21, 2013. <http://www.basic.ncsu.edu/dsl/slr.html>.
- South Carolina Department of Natural Resources. 2012. "An Information/Education Series from the Marine Resources Division." *Sea Science*. Accessed September 20, 2013. <http://www.dnr.sc.gov/marine/pub/seascience/shrimp.html>.
- Stepzinski, Teresa. 2011. "Georgia Shrimp Season Could Be Delayed." *The Florida Times-Union*, April 9. Accessed October 30, 2013. <http://jacksonville.com/news/georgia/2011-04-09/story/georgia-shrimp-season-could-be-delayed>.
- Sullivan, Buddy. 2002. "Darien." *New Georgia Encyclopedia Online*. Accessed October 13, 2013. <http://www.georgiaencyclopedia.org/articles/counties-cities-neighborhoods/darien>.
- Sumaila, U. Rashid, William Cheung, Vicky Lam, Daniel Pauly, and Samuel Herrick. 2011. "Climate Change Impacts on the Biophysics and Economics of World Fisheries." *Nature Climate Change*, November 20. Accessed November 15, 2013. doi:10.1038/NCLIMATE1301.
- Taylor, B.M., B.P. Harman and M. Inman. 2013. "Scaling-up, scaling-down, and scaling-out: Local planning strategies for sea-level rise in New South Wales, Australia." *Geographical Research* 51 (3): 292-303.
- Tisdell, Clem. "Economic Aspects of Ecotourism: Wildlife Based Tourism and its Contribution to Nature," *Sri Lankan Journal of Agricultural Economics* 5 (2003): 83-95 <http://dx.doi.org/10.4038/sjae.v5i0.3478>
- Van Den Avyle, Michael J, Fowler, Dean L. 1984. "Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic): Blue Crab," March. Georgia Cooperative Fishery Research Unit, School of Forest Resources, University of Georgia.
- Wang, Long-Uong, and Jiann-Chu Chen. 2005. "The Immune Response of White Shrimp *Litopenaeus vannamei* and its Susceptibility to *Vibrio alginolyticus* at Different Salinity Levels." *Fish & Shellfish Immunology* 18: 269-278.
- Water Research Foundation. 2012. "Estimating Salinity Effects Due to Climate Change on the Georgia and South Carolina Coasts." Accessed November 17, 2013. <http://pubs.usgs.gov/sir/2013/5036/pdf/sir2013-5036.pdf>
- Water Quality in Georgia 2006-2007. 2008. "Chapter 4 Wetlands Wetland Programs." Accessed October 12 2013. [http://www.gaepd.org/Files\\_PDF/305b/Y2008\\_303d/Y2008\\_Cover-Chapter3\\_305b.pdf](http://www.gaepd.org/Files_PDF/305b/Y2008_303d/Y2008_Cover-Chapter3_305b.pdf)
- West, J.J. and M.J. Small. 2001. "Storms, investor decisions, and the economic impacts of sea level rise." *Climatic Change* 48 (2/3): 317.
- Whitaker, J. David. 2010. "An Information/Education Series from the Marine Resources Division: Blue Crabs." South Carolina Department of Natural Resources. Accessed November 15, 2013. <http://www.dnr.sc.gov/marine/pub/seascience/bluecrab.html>

- Whitaker, J. David, Rachel King, and David Knott. 2010. "Jellyfish." South Carolina Department of Natural Resources. Accessed October 23, 2013.  
<http://www.dnr.sc.gov/marine/pub/seascience/jellyfi.html>.
- Więski, Kazimierz, Hongyu Guo, Christopher B. Craft, and Steven C. Pennings. 2010. "Ecosystem Functions of Tidal Fresh, Brackish, and Salt Marshes on the Georgia Coast." *Estuaries And Coasts* 1: 161. JSTOR Life Sciences, EBSCOhost. Accessed September 17, 2013.
- Yohe, G., J. Neumann and H. Ameden. 1995. "Assessing the economic cost of greenhouse-induced sea level rise: Methods and application in support of a national survey." *Journal of Environmental Economics and Management* 3: S.78.
- Yohe, G., K. Knee and P. Kirshen. 2011. "On the economics of coastal adaptation solutions in an uncertain world." *Climatic Change* 106 (1): 71-92.
- Zein-Eldin, Zoula P. 1996. "Effect OF Salinity on Growth of Postlarval Penaeid Shrimp." *Bureau of Commercial Fisheries*: 188-96.